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Radian Corp., Austin, TX

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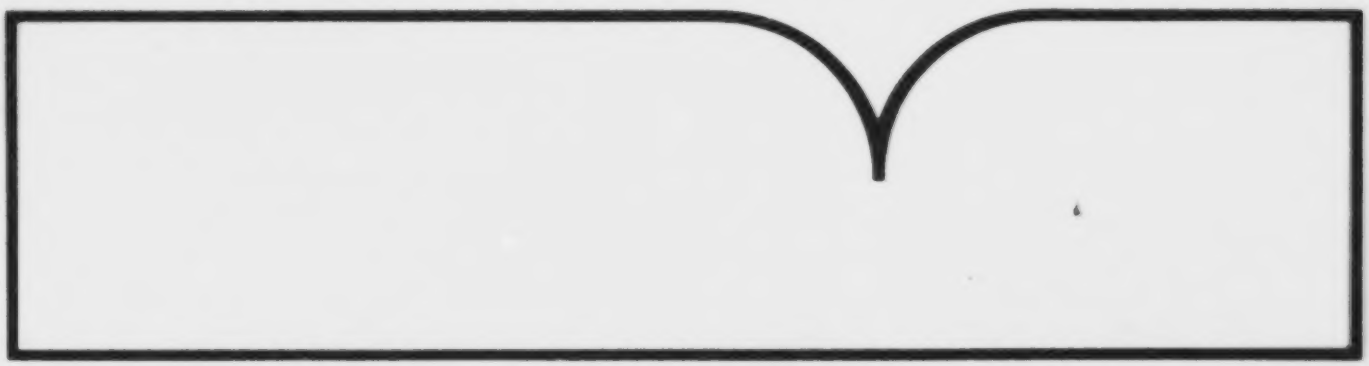

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16. ABSTRACT The manual summarizes technical information that will assist in identifying and controlling hydrogen fluoride release hazards specific to the South Coast Air Quality Management District (SCAQMD) of southern California. The SCAQMD has considered a strategy for reducing the risk of a major accidental air release of toxic chemicals. The strategy includes monitoring the storage, handling, and use of certain chemicals and provides guidance to industry and communities. Anhydrous hydrogen fluoride, a corrosive liquid that boils at room temperature, rapidly absorbs moisture to form highly corrosive hydrofluoric acid. Hydrogen fluoride gas has an IDLH (immediately dangerous to life and health) concentration of 20 ppm, which makes it a substantial acute toxic hazard. Reducing the risk associated with an accidental release of hydrogen fluoride involves identifying some of the potential causes of accidental releases that apply to the processes that use hydrogen fluoride in the SCAQMD. This manual identifies examples of potential causes as well as measures that may be taken to reduce the accidental release risk. Such measures include recommendations on: plant design practices; prevention, protection, and mitigation technologies; and operation and maintenance practices. Conceptual cost estimates of possible prevention, protection, and mitigation steps are provided.

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Hydrogen Fluoride	Storage	Stationary Sources	07B 15E
Alkylation	Materials Handling	Accidental Releases	07C
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ABSTRACT

The South Coast Air Quality Management District (SCAQMD) of southern California has considered a strategy for reducing the risk of a major accidental air release of toxic chemicals. The strategy includes monitoring the storage, handling, and use of certain chemicals and providing guidance to industry and communities. This manual summarizes technical information that will assist in identifying and controlling release hazards specific to the SCAQMC associated with hydrogen fluoride.

Anhydrous hydrogen fluoride has an IDLH (Immediately Dangerous to Life and Health) concentration of 20 ppm, which makes it a substantial acute toxic hazard. Reducing the risk associated with an accidental release of hydrogen fluoride involves identifying some of the potential causes of accidental releases that apply to the processes that use hydrogen fluoride in the SCAQMD. In this manual examples of potential causes are identified as are specific measures that may be taken to reduce the accidental release risk. Such measures include recommendations on plant design practices, prevention, protection and mitigation technologies, and operation and maintenance practices. Conceptual cost estimates of possible prevention, protection, and mitigation measures are provided.

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SECTION 1
INTRODUCTION

1.1 BACKGROUND

Recognizing the risk associated with accidental releases of air toxics in southern California, the South Coast Air Quality Management District (SCAQMD) conducted a study in 1985 to determine the presence, quantities, and uses of hazardous chemicals in the SCAQMD, which comprises Los Angeles, Orange, San Bernadino, and Riverside Counties. The SCAQMD study resulted in a report entitled "South Coast Air Basin Accidental Toxic Air Emissions Study," which outlined an overall strategy for reducing the potential for a major toxic chemical release incident.

The strategy includes: monitoring industry activities associated with the storage, handling, use, and manufacture of certain chemicals; using the best technical information available; and guiding industry and communities in minimizing the potential for accidental releases as well as the consequences of any releases that might occur.

Historically, there do not appear to have been any significant releases of hydrogen fluoride in the SCAQMD. Major incidents elsewhere involving hydrogen fluoride do not appear to have been common, although a release of uranium hexafluoride in Oklahoma in early 1986 decomposed to hydrogen fluoride and resulted in at least one death and some injuries.

1.2 PURPOSE OF THIS MANUAL

This manual compiles technical information on hydrogen fluoride and on the prevention of accidental releases of hydrogen fluoride. The manual addresses and summarizes issues relating to release prevention associated with

the storage and handling of hydrogen fluoride, and with process operations involving hydrogen fluoride as it is used in the SCAQMD.

This manual is not intended to be a specification manual, and in fact refers the reader to technical manuals and other sources for more complete information on the topics discussed. Other sources include manufacturers and distributors of hydrogen fluoride and technical literature on design, operation, and loss prevention in facilities handling toxic chemicals.

1.3 USES OF HYDROGEN FLUORIDE

Hydrogen fluoride (HF) is a significant commodity chemical produced by sulfuric acid treatment of calcium fluoride in the natural mineral fluorspar. Its primary use is in the manufacture of inorganic fluorides, chlorofluorocarbons and other fluorochemicals, uranium processing, glass etching and polishing, steel pickling, and petroleum alkylation. Numerous references in the technical literature describe the manufacture and uses of hydrogen fluoride. In the SCAQMD, hydrogen fluoride does not seem to be manufactured, but apparently it is used in the alkylation process and in the manufacture of chlorofluorocarbons. Some limited survey data indicate that the predominant uses of hydrogen fluoride in the SCAQMD are (1):

- As a catalyst in petroleum refinery alkylation;
- As a reactant in chlorofluorocarbon manufacture; and
- In repackaging.

Survey data on other possible uses for hydrogen fluoride were unavailable.

Hydrogen fluoride is stored in small cylinders, railroad tank cars used for stationary storage, and bulk storage tanks.

In addition to anhydrous hydrogen fluoride (hydrogen fluoride gas), the use of hydrofluoric acid, an aqueous solution of hydrogen fluoride, was also reported by some survey respondents. Uses of this acid could not be determined from the survey data, but it might be used in some specialty chemical syntheses or in industrial cleaning or etching processes.

1.4 ORGANIZATION OF THE MANUAL

Following the introductory section, the remainder of the manual presents technical information on specific hazards and categories of hazards and their control as they relate to hydrogen fluoride.

Section 2 discusses physical, chemical, and toxicological properties of hydrogen fluoride. Section 3 describes the types of facilities that use hydrogen fluoride in the SCAQMD and process hazards associated with these facilities. Hazard prevention and control are discussed in Section 4, as are the costs of example storage and process facilities reflecting different levels of control through alternative systems. The examples are for illustration only and do not necessarily represent a satisfactory alternative control option in all cases. Section 5 contains references. Appendix A presents a listing of the electromotive series of metals. Appendix B is a glossary of key technical terms that might not be familiar to all users of the manual, and Appendix C presents selected conversion factors between metric (SI) and English measurement units.

SECTION 2
CHEMICAL CHARACTERISTICS

This section of the report describes the physical, chemical, and toxicological properties of hydrogen fluoride as they relate to accidental release hazards.

2.1 PHYSICAL PROPERTIES

Anhydrous hydrogen fluoride, which is a clear, colorless, corrosive liquid with a pungent, irritating odor, has a boiling point of about 67°F at atmospheric pressure. Hydrogen fluoride is hygroscopic and fumes upon exposure to moist air. In aqueous solutions hydrogen fluoride becomes hydrofluoric acid, a highly corrosive liquid. Concentrated aqueous solutions also boil at relatively low temperatures and fume on contact with moist air. The physical properties of anhydrous and aqueous hydrofluoric acid are listed in Tables 2-1 and 2-2, respectively (2).

Because of the relatively low boiling point of hydrogen fluoride, spills and leaks of liquid can result in hazardous releases to the atmosphere that are nearly as severe as direct gas or vapor releases. Also, since the vapor density of hydrogen fluoride is greater than that of air, releases remain close to the ground and could create a potentially dangerous situation for workers and surrounding communities.

Since liquid hydrogen fluoride has a large coefficient of thermal expansion, liquid-full equipment is a special hazard. A liquid-full vessel is a full vessel that is not vented and that has little or no vapor space above the liquid. A liquid-full line is a section of pipe sealed off at both ends and full of liquid hydrogen fluoride, with little or no vapor space. In such

TABLE 2-1. PHYSICAL PROPERTIES OF HYDROGEN FLUORIDE

		Reference
CAS Registry Number	07664-39-3	
Chemical Formula	HF	
Molecular Weight	20.01	
Normal Boiling Point	67.12 °F @ 14.7 psia	2
Melting Point	-118.4 °F	2
Liquid Specific Gravity (H_2O=1)	0.991 @ 67.15 °F	3
Vapor Specific Gravity (air=1)	2.4 @ 68 °F	4
Vapor Pressure	17.8 psia @ 77 °F	2
Vapor Pressure Equation		5

$$\log Pv = A - \frac{B}{T+C}$$

where: Pv = vapor pressure, mm Hg
T = temperature, °C
A = 7.68098, a constant
B = 1,475.60, a constant
C = 287.88, a constant

Liquid Viscosity	0.256 centipoise @ 32 °F	5
Solubility in Water	Complete	2
Specific Heat at Constant Volume (vapor)	0.55 Btu/(lb-°F) @ 68 °F	2

(Continued)

TABLE 2-1 (Continued)

		Reference
Specific Heat at Constant Pressure (vapor)	2.99 Btu/(lb-°F) @ 68 °F	2
Specific Heat at Constant Pressure (liquid)	0.62 Btu/(lb-°F) @ 68 °F	2
Latent Heat of Vaporization	1.62 Btu/lb @ 67.15 °F	5
Liquid Surface Tension	10.1 dynes/cm @ 32 °F	2
Average Coefficient of Thermal Expansion, 0-60°F	0.00112/°F	6
Additional properties useful in determining other properties from physical property correlations:		
Critical Temperature	370 °F	2
Critical Pressure	940 psia	2
Critical Density	18.10 lb/ft^3	2
Energy of Molecular Interaction	355 K	7
Effective Molecular Diameter	3.240 Angstroms	7

TABLE 2-2. PHYSICAL PROPERTIES OF 70% AQUEOUS HYDROFLUORIC ACID

		Reference
Boiling Point	152.06 °F @ 14.7 psia	6
Freezing Point	-94.3 °F	6
Vapor Pressure	1.1. psia @ 32 °F	6
Specific Gravity (H_2O = 1)	1.258 @ 32-39.2 °F	6
Specific Heat	0.75 Btu/(lb-°F) @ 64-68 °F	6

cases, there is no room for thermal expansion of the liquid and temperature increases can result in containment failure.

2.2 CHEMICAL PROPERTIES AND REACTIVITY

Hydrogen fluoride, whether anhydrous or in aqueous solutions, is a highly reactive chemical. The most significant chemical properties contributing to the potential for releases are as follows (2,8):

- Anhydrous hydrogen fluoride rapidly absorbs moisture to form highly corrosive hydrofluoric acid. Hydrofluoric acid is corrosive to most metals and results in the formation of hydrogen gas in the presence of moisture. This corrosiveness can lead to equipment failure, and the potential buildup of hydrogen gas in confined areas presents a fire and explosion hazard.

- Hydrogen fluoride reacts with metals listed above hydrogen in the Electromotive Series of Metals (a ranking of metals based on standard electrode potentials, see Appendix A,

page 112) to form fluoride salts. In addition, it reacts with metal carbonates, oxides, and hydroxides. Accumulation of these fluoride compounds can render valves and other close-fitting moving parts inoperable in a process system, causing possible equipment or process failures. Such compounds also can contribute to the fouling of critical heat transfer surfaces in process operations. Hydrogen fluoride also attacks glass, silicate ceramics, leather, natural rubber, and wood, but does not promote their combustion.

- Considerable heat evolves when anhydrous hydrogen fluoride or concentrated hydrofluoric acid is diluted with water. Violent reactions can result from the inappropriate addition of water or caustic solutions to these materials.

- Anhydrous hydrogen fluoride and hydrofluoric acid react with silica (SiO_2) and SiO_2-containing substances to form silicon tetrafluoride (SiF_4) and fluorosilicic acid. SiF_4, a colorless gas at ambient temperatures, is highly toxic. An equilibrium mixture of SiF_4 in the presence of moisture also contains hydrogen fluoride and hydrofluoric acid.

- Anhydrous hydrogen fluoride and hydrofluoric acid react exothermally with organic and inorganic reducing agents, but do not promote their combustion.

- Anhydrous hydrogen fluoride reacts with cyanides and sulfides to produce toxic hydrogen cyanide and hydrogen sulfide. This can result in potentially explosive mixtures in confined areas since both hydrogen cyanide and hydrogen sulfide are flammable.

2.3 TOXICOLOGICAL AND HEALTH EFFECTS

Hydrogen fluoride is a highly toxic and highly corrosive and severe irritant to the skin, eyes, and respiratory system. The toxicology of hydrogen fluoride has been explored through accidental human exposure and through studies on animals (9,10,11,12,13). The acute effects of very short-term exposure to elevated concentrations of hydrogen fluoride, however, are not well documented.

The concentrations at which various acute effects occur vary significantly with the exposure time and with the individual. For instance, inhalation of 50 parts per million (ppm) hydrogen fluoride for 30 to 60 minutes might be fatal, while a concentration of 110 ppm inhaled for 1 minute might be tolerated, causing only the initial onset of toxic effects. Less severe exposures cause irritation of the nose and eyes, smarting of the skin, and some degree of conjunctival and respiratory irritation. More serious exposures can lead to severe irritation of the eyes and eyelids, ulceration of the skin, inflammation and congestion of the lungs, and eventual cardiovascular collapse and death. Additional effects may include dyspnea, bronchopneumonia, cyanosis, shock, muscle spasms, convulsions, parasthesias, jaundice, oliguria, albuminuria, hematuria, nausea, vomiting, abdominal pain, diarrhea, and burns of the mouth, esophagus, and digestive tract. A concentration of 20 ppm has been designated as the IDLH (Immediately Dangerous to Life and Health), which is based on a 30-minute exposure. Table 2-3 summarizes some of the relevant exposure limits for hydrogen fluoride. Table 2-4 presents a summary of the predicted human health effects after exposure to various concentrations of hydrogen fluoride.

TABLE 2-3. EXPOSURE LIMITS FOR HYDROGEN FLUORIDE

Exposure Limit	Concentration (ppm)	Description	Reference
IDLH	20	The concentration defined as posing an immediate danger to life and health (i.e. causes toxic effects for a 30-minute exposure).	14
PEL	3	A time-weighted 8-hour exposure to this concentration, as set by the Occupational Safety and Health Administration (OSHA), should result in no adverse effects for the average worker.	10
LC_{LO}	50	This concentration is the lowest published lethal concentration for a human over a 30-minute exposure.	10
TC_{LO}	110	This concentration is the lowest published concentration causing toxic effects (irritation) for a 1-minute exposure.	10

TABLE 2-4. PREDICTED HUMAN HEALTH EFFECTS OF EXPOSURE TO VARIOUS CONCENTRATIONS OF HYDROGEN FLUORIDE

ppm	Predicted Effect
0.5 - 3	Odor threshold
2	Repeated 6-hour exposures can result in stinging eyes and facial skin, and nasal irritation
>10	Possible lung injury
>50	Vapor is intolerably irritating and causes damage to the lungs; inhalation may result in serious injury

Source: Reference 11

SECTION 3
FACILITY DESCRIPTIONS AND PROCESS HAZARDS

This briefly describes the uses of hydrogen fluoride in the SCAQMD and highlights major process hazards related to accidental releases. Preventive measures associated with these hazards are discussed in Section 4.

3.1 PROCESSING

According to the survey data, the primary uses for hydrogen fluoride in the SCAQMD appear to be chlorofluorocarbon manufacturing and petroleum alkylation. This subsection summarizes the major technical features of typical processing and storage facilities found in the SCAQMD and discusses accidental release hazards associated with them.

3.1.1 Hydrogen Fluoride Alkylation

A major use of hydrogen fluoride in the petroleum refining industry is for the alkylation of olefinic hydrocarbons. In this process, anhydrous hydrogen fluoride is used as a liquid catalyst in the production of octane improvers for gasoline.

Figures 3-1 shows a block diagram of one of several possible configurations for a hydrogen fluoride alkylation process. Processes differ primarily in the configuration of the reactor/settler section and in whether or not they include a depropanizer unit (15).

Before entering the alkylation unit, the olefin-containing feed is treated to remove sulfur compounds and water. The feed is mixed with hydrofluoric acid and recycled isobutane, and the combined stream is fed to the

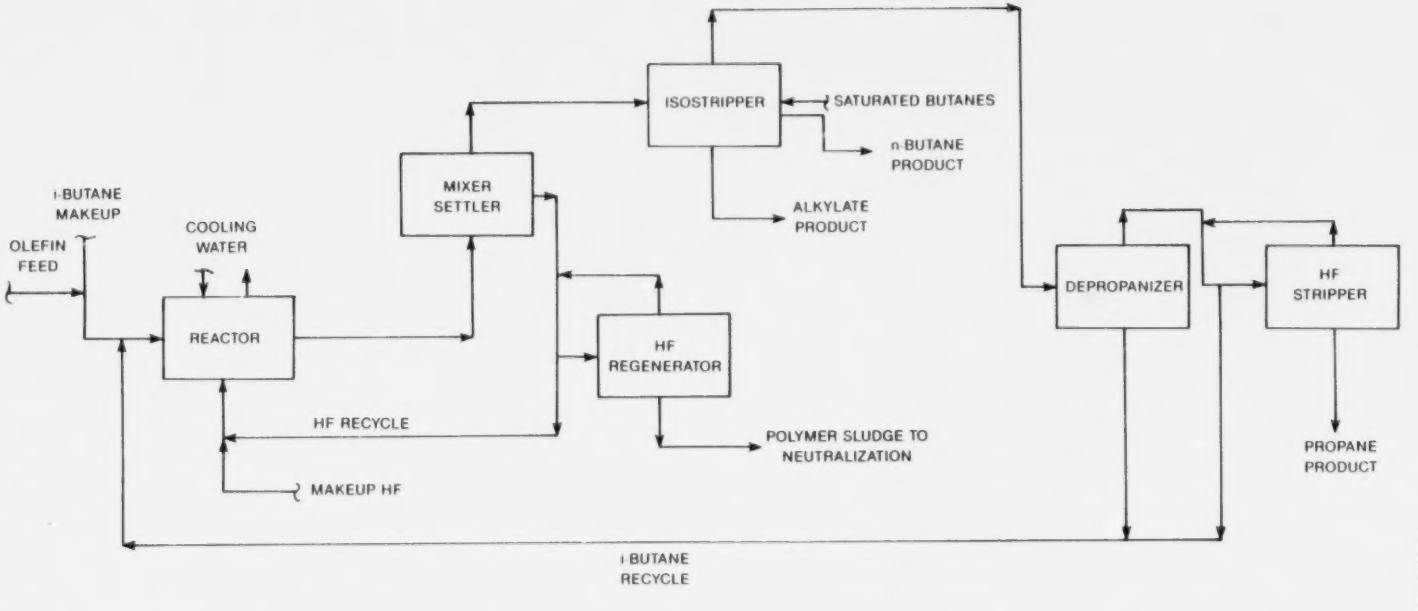

Figure 3-1. Conceptual diagram of typical hydrogen fluoride alkylation process.

reactor vessel. The alkylation reactor operates at a temperature in the range of 75-100°F and at a pressure of 80-115 pounds per square inch gage (psig) (15). Cooling water in a heat-exchange-tube bundle inside the alkylation reactor is commonly used in hydrogen fluoride alkylation to remove the heat generated by the exothermic reaction. The acid and organic phases of the reactor effluent separate in the settler, and the acid recycles to the reactor. A small portion of the acid is sent to a regenerator column, where relatively pure hydrogen fluoride is distilled from a minor amount of heavy organic compounds and water. The settler organic phase is fed to a fractionator, the isostripper, where isobutane and lighter components are separated. The bottoms product from the isostripper is motor alkylate. A portion of the isostripper overhead is depropanized with propane, containing some hydrogen fluoride, taken as an overhead stream. The propane is stripped of hydrogen fluoride and recovered as a bottoms stream.

From a hydrogen fluoride release perspective, a fundamental characteristic of the alkylation process is the use of hydrogen fluoride as a catalyst rather than as a reactant. Only a small portion of the hydrogen fluoride catalyst is consumed in the alkylation process, approximately 0.002 - 0.007 lb/gal of product (15), and therefore the process has a number of critical areas where hydrogen fluoride is present in high concentrations or in relatively pure form.

High hazard areas in the alkylation process, excluding bulk storage and transfer (discussed in Section 3.3), include the following:

- Feed treatment to remove water and sulfur compounds from the hydrocarbon feed;
- Reactor;
- Heat-exchanger-tube bundle within the reactor;

- Reactor cooling system;
- Hydrogen fluoride recycle circuits, including the settler;
- Hydrogen fluoride distillation, (the regenerator column); and
- Hydrogen fluoride stripping (from propane).

The feed treatment process to remove water and sulfur is a critical area of the process because these compounds promote corrosion. Water and hydrogen fluoride combine to form hydrofluoric acid, which rapidly attacks many materials including carbon steel. A properly designed alkylation system should use materials, of construction that take this corrosion potential into account and that allow a certain feed moisture concentration to be maintained. Deficiencies or failures in the water removal system could lead to a protracted corrosion problem resulting eventually in equipment failure. Sulfur compounds also can lead to corrosion with results similar to those of water.

The reactor itself operates under mild conditions with near ambient temperatures. Since the reactor is a pressure vessel with an exothermic reaction, the potential exists for a runaway reaction resulting in overheating and overpressure. The normal elevated operating pressure, combined with the adverse effects of corrosion, could cause an equipment failure even under normal operating conditions. Proper system design must anticipate these hazards and incorporate appropriate safeguards. These safeguards should include highly reliable reactant feed control, pressure relief, and reactor cooling system controls and backup.

The presence of a heat-exchange-tube bundle within the reactor presents a potential hazard from tube leakage since water is used as the cooling medium. Small leaks over time could cause corrosion and eventually a failure. Also,

since the reactor operates at pressures above typical cooling water circuit pressures, undetected leakage of acid into the cooling system could contribute to protracted corrosion and ultimately to a cooling system failure. A cooling system failure could lead to a runaway reaction.

Hydrogen fluoride recycle circuits are subject to corrosion, with general vessel, piping, valve, or pump failures. Because the hydrogen fluoride is recycled, traces of moisture may enter the system and concentrate in the recycle stream, thus contributing to corrosion.

Hydrogen fluoride distillation and stripping unit operations are subject to potential overheating and overpressure since these operations have a thermal energy input. Loss of cooling in condensers could be a cause of overpressure. The reboilers and bottoms pumps are potential weak points in these systems since operating conditions are severe.

Since the alkylation process uses and produces highly flammable materials, other potential hazards associated with the entire process are fire and explosion. A fire or explosion clearly could cause a release. An additional consideration is that hydrogen is formed as a corrosion product in the alkylation process. Rapid corrosion in any part of the system also carries with it an ignition potential because of possible hydrogen gas buildup.

3.1.2 Manufacture of Chlorofluorocarbons

A second principal use of hydrogen fluoride in the SCAQMD is in the manufacture of chlorofluorocarbons. One commercially important method of production is the successive replacement of chlorine in chlorinated hydrocarbon feedstocks (chlorocarbons) using hydrogen fluoride as a source of fluorine. A block diagram of a typical liquid phase chlorofluorocarbon manufacturing process is presented in Figure 3-2.

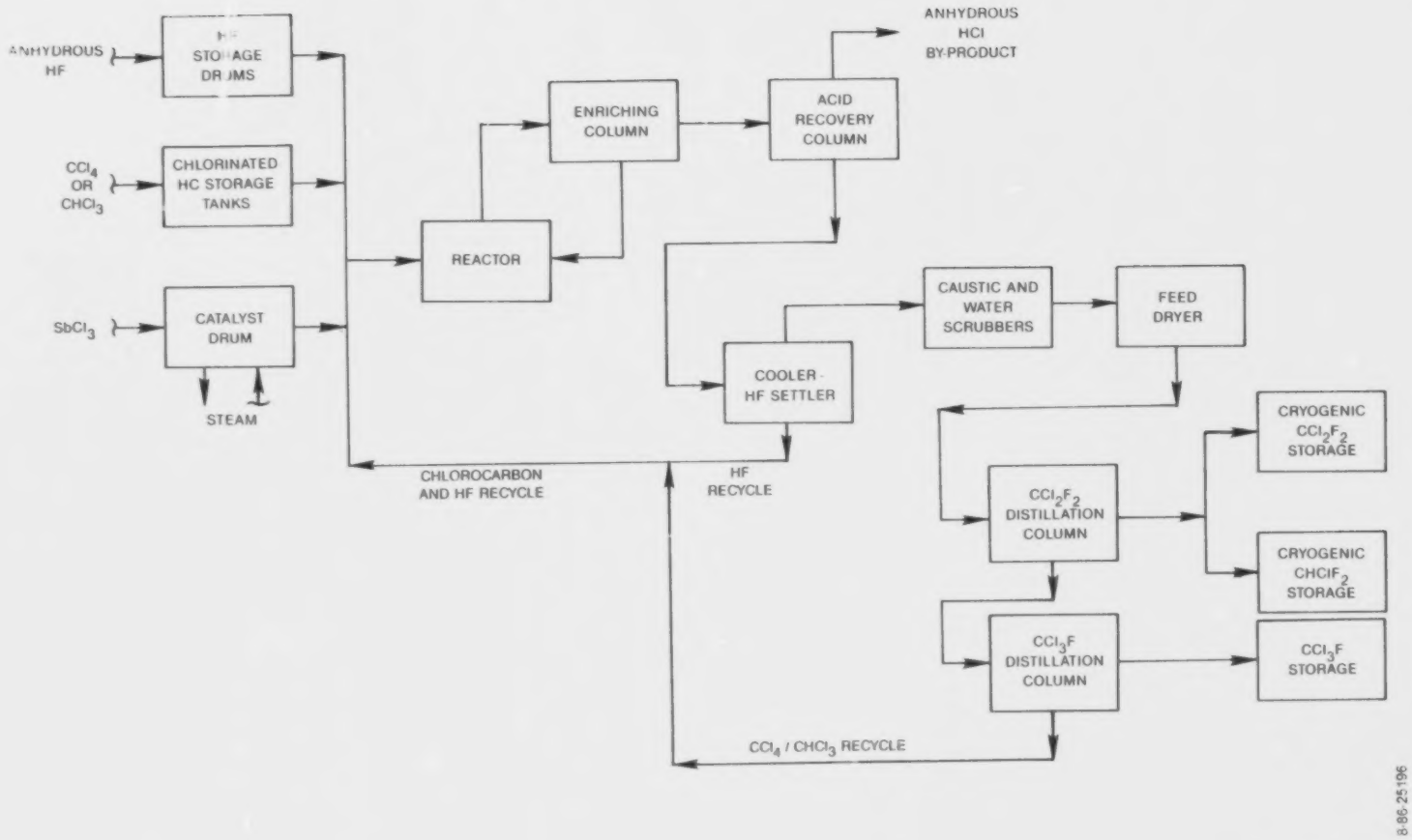

Figure 3-2. Conceptual diagram of typical chlorofluorocarbon process.

The liquid-phase reaction system for the manufacture of chlorofluorocarbons consists of a heated reaction vessel containing catalyst dissolved in a mixture of chlorocarbon, and partially fluorinated intermediates recycled to the reactor from downstream processing. Antimony pentafluoride, or a mixture of antimony trifluoride and chlorine, is typically used as catalyst. Liquid hydrogen fluoride and chlorocarbon are fed to the reactor. The reactor typically operates at a temperature and pressure of approximately 176°F and 100 psig, respectively (15). Although the fluorination reactions are exothermic, additional heat is added to the reactor because the reactor also serves as a reboiler for an enriching column. Crude product vapors evolved from the reactor are fed directly to the enriching column. The column is positioned so that the liquid bottoms flow by gravity as recycle to the reactor.

After being withdrawn from the enriching column, a stream containing hydrogen chloride, hydrogen fluoride, and the chlorofluorocarbon products is sent to an acid recovery column. This column typically operates at approximately 100 psig (15). Hydrogen chloride concentrates at the top of the column and is recovered as a by-product. The bottoms contain the product fluorocarbons and residual hydrogen fluoride at a temperature of approximately 122°F (15). The hydrogen fluoride is removed in a hydrogen fluoride settler and is recycled to the reactor system. The mutual solubility of hydrogen fluoride and the fluorocarbons is temperature dependent and temperatures as low as -22°F are often required (15).

Trace impurities are removed from the fluorocarbon products by scrubbing with water and a dilute caustic solution. Following the scrubbing operations, the product stream is dried and fractionated into various chlorofluorocarbon products.

High hazard areas in the chlorofluorocarbon manufacturing process, excluding bulk storage and transfer (discussed in Section 3.3), include the following:

- Feed treatment to remove water from the chlorocarbon feed streams;
- Reactor;
- Enriching and acid recovery columns;
- Hydrogen fluoride recovery unit; and
- Hydrogen fluoride recycle system.

Concerns for moisture removal in the feed treatment process are the same as those associated with alkylation feed treatment (Section 3.1.1).

An exothermic reaction occurs in the chlorofluorocarbon process, but since the reactor also serves as a reboiler to an enriching column, a reactor cooling system is not required for heat removal. In fact, additional heat is added. A potential hazard is overheating and overpressure caused by a malfunction in the temperature control system. Overheating and overpressure could also be caused by a loss of cooling in the enriching column condenser. Similar considerations apply to the other columns.

The hydrogen fluoride recycle system presents the hazards of vessel, piping, valve, and pump failure from potential corrosion caused by a buildup of trace quantities of water in the system.

3.2 REPACKAGING

In the SCAQMD it appears that anhydrous hydrogen fluoride and hydrofluoric acid are repackaged for resale and further use. Aqueous hydrofluoric acid is typically repackaged into drums and carboys, while anhydrous hydrogen fluoride is commonly repackaged into cylinders. Hazards associated with this

operation include overpressure, overfilling, mechanical damage, fire exposure, and chemical contamination.

A filling operation is usually carried out by transferring hydrogen fluoride from a bulk storage vessel using specially designed filling systems similar to those used for chlorine (16). Protective barriers are sometimes used to separate the transfer storage tank from the cylinder or drum being filled to prevent damage from shrapnel as a result of a possible rupture of the cylinder or drum (17).

Equipment used in repackaging operations should be constructed from materials compatible with hydrogen fluoride or hydrofluoric acid, depending on the operations. Relief systems are usually incorporated into the transfer system to prevent possible equipment ruptures. In addition, care usually is taken to prevent overfilling of drums and cylinders.

3.3 STORAGE AND TRANSFER

Because of its relatively low boiling point and high vapor pressure, anhydrous hydrogen fluoride is stored in pressure vessels. Hydrogen fluoride is also stored in cylinders for small-scale use and is shipped by tank car and tank truck. Figures 3-3 and Figure 3-4 show typical storage and transfer operations. These figures are only conceptual representations of storage and transfer operations. Actual transfer systems may vary in the design and method of transfer. Moderate quantities of hydrogen fluoride may be stored as a pressurized and liquified gas. Larger quantities are usually stored at atmospheric pressure, as refrigerated liquids in single and double-walled horizontal cylindrical or spherical vessels. Vendors or process licensors should be consulted for detailed specifications on recommended storage facilities (8,18,19,20,21).

Hydrofluoric acid is transferred to storage either by pumps or by compressed gas pressure. If compressed gas is used, it should first be dried to

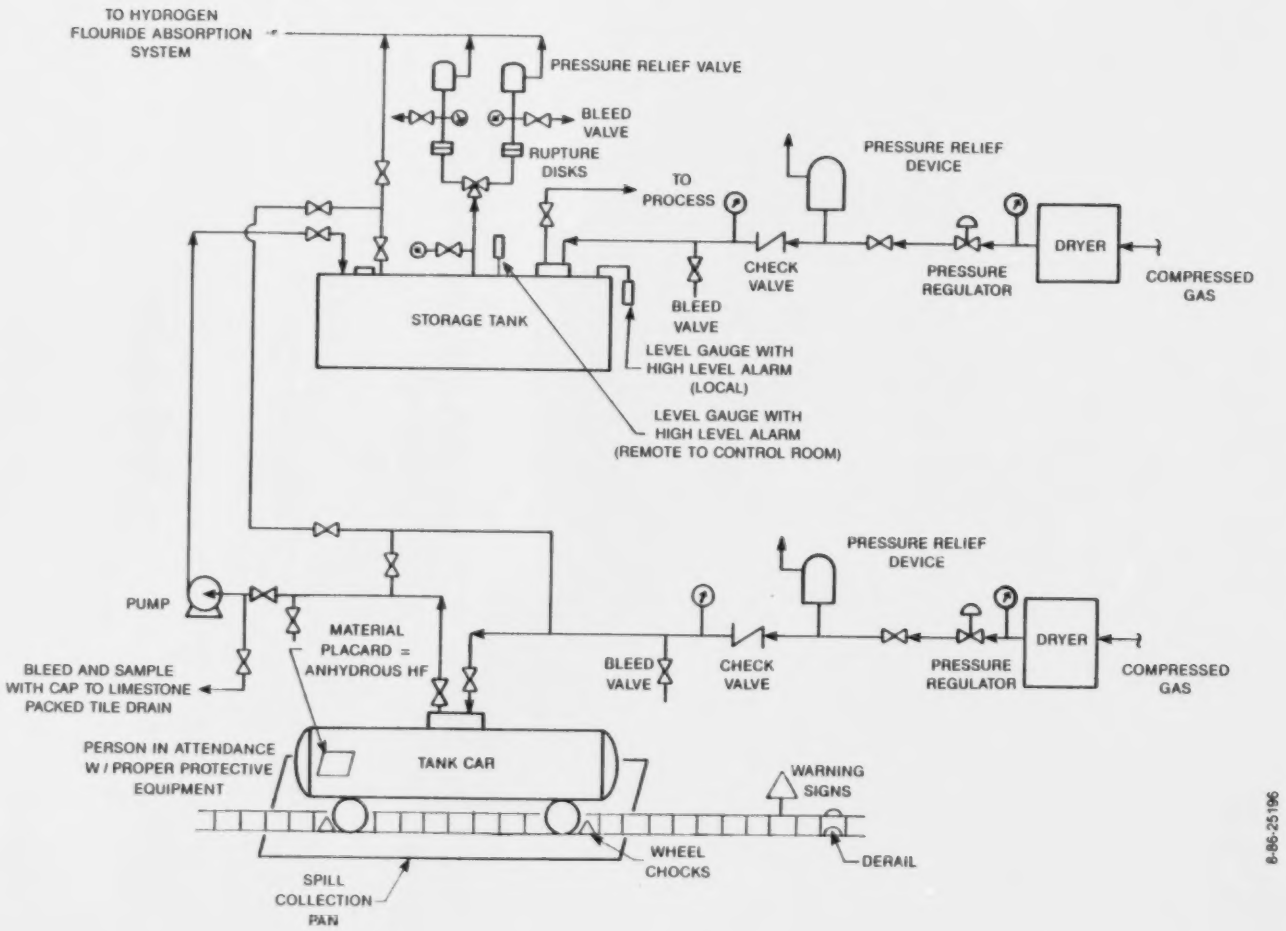

Figure 3-3. Conceptual process diagram of hydrogen fluoride rail tank car unloading and tank storage facility.

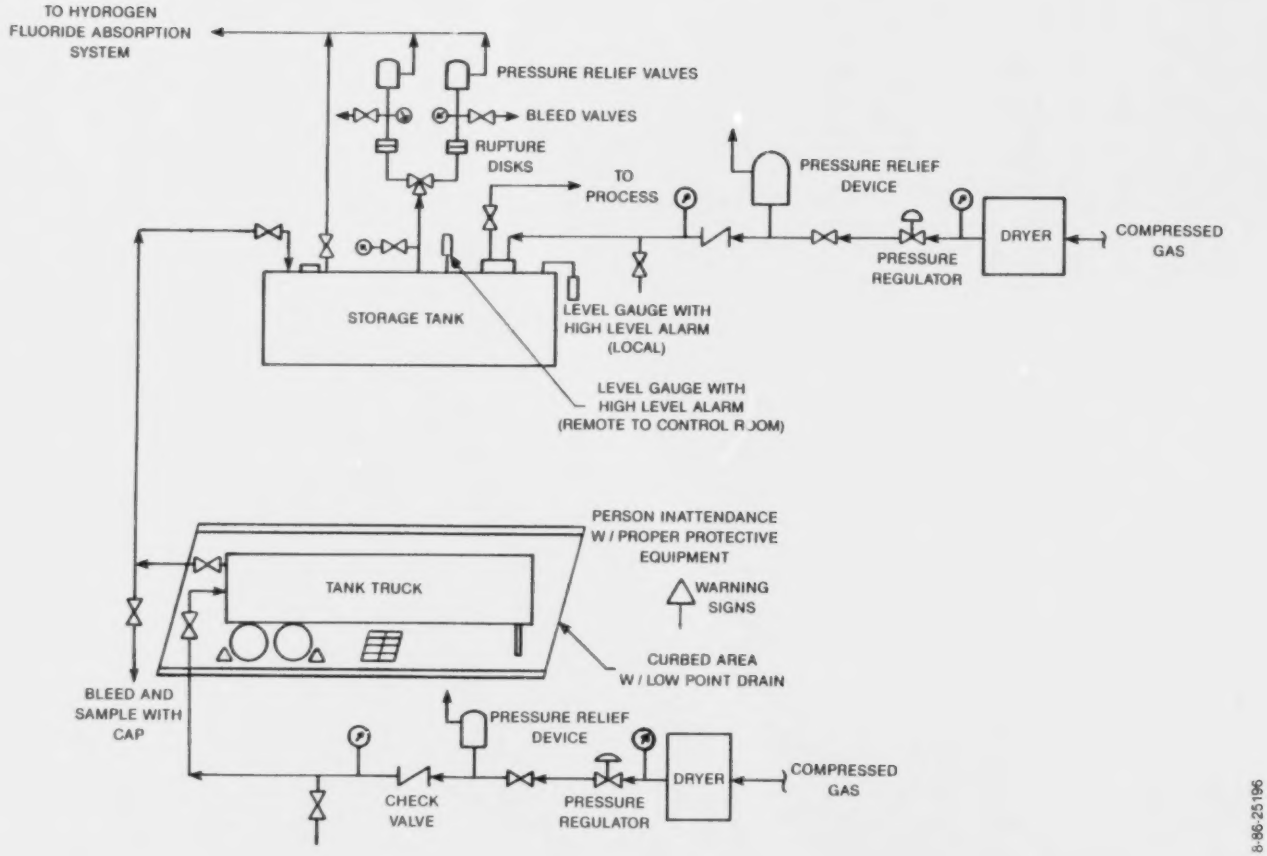

Figure 3-4. Conceptual process diagram of hydrogen fluoride tank truck unloading and tank storage facility.

a moisture content equivalent to air at -22°F dew point to prevent corrosion of the storage and transfer vessels (8). For anhydrous hydrofluoric acid, nitrogen or hydrocarbon gas is usually used. If a hydrocarbon is used, air must be excluded to avoid a possible flammable mixture that would be a significant release hazard. If air is used, corrosion can occur as a result of oxygen dissolution in the acid, since hydrogen fluoride is commonly stored in carbon steel tanks.

For safety reasons, pump transfer is commonly preferred over compressed gas transfer. The pumps most commonly used are centrifugal, rotary, positive displacement or sealless, depending on the specific situation. In addition, self-priming pumps are commonly used since they can provide sufficient discharge pressure for transfer to distant or elevated storage areas, thus avoiding the hazards associated with dry gas priming of the pump.

3.4 POTENTIAL CAUSES OF RELEASES

Both anhydrous hydrogen fluoride and hydrofluoric acid can be used safely in appropriate processing and storage equipment. However, when exposed to the atmosphere, hydrogen fluoride vaporizes readily and, because of its strong affinity for water, combines with moisture in the air to form hydrofluoric acid. This acid can be detected in air by its white fumes, pungent odor and irritant property.

Hydrogen fluoride releases can originate from many sources, including leaks or ruptures in vessels, piping, valves, instrumentation connections, and process machinery such as pumps and compressors. Specific potential release sources within processes dominant in the SCAQMD were identified in preceding subsections of this manual.

Potential hydrogen fluoride releases may be liquid or vapor. Liquid spills can occur when anhydrous hydrogen fluoride is released at or below its boiling point of 67°F or when a sudden release of hydrogen fluoride above this

temperature results in vapor flashing, which cools the remainder of the chemical to 67°F. Direct releases of vapor or gas also can occur. Liquid spills of hydrofluoric acid can release some hydrogen fluoride as well. However, the vapor pressure resulting from the concentrated acid is considerably less than the vapor pressure of pure hydrogen fluoride. Nonetheless, the threat from the acid should not be discounted, especially if spills occur on hot surfaces where evaporation rates are high.

Failures leading to accidental releases may be broadly classified as due to process, equipment, or operational failures. Causes of releases discussed below are intended to be illustrative, not exhaustive.

3.4.1 Process Causes

Process causes are related to the fundamentals of process chemistry, control and to general operation. Possible process causes of a hydrogen fluoride release include:

- Excess olefin feed to an alkylation reactor leading to excessive exothermic reaction, combined with failure of the cooling system;
- Backflow of alkylation process reactants to a hydrogen fluoride feed tank;
- Inadequate water and sulfur removal from hydrocarbon feeds to the alkylation process over a long period of time leading to progressive corrosion;
- Excess feeds in any part of the system leading to overfilling or overpressuring equipment;
- Loss of condenser cooling in distillation units; and

- Overpressure in hydrogen fluoride storage vessels due to overheating or overfilling. These situations may be caused by exothermic reactions from contamination, fire exposure, or unrelieved overfilling.

3.4.2 Equipment Causes

Equipment causes of accidental releases result from hardware failures. Some possible causes include:

- Excessive stress due to improper fabrication, construction, or installation;

- Failure of vessels at normal operating conditions due to weakening of equipment from excessive stress, external loadings, or corrosion. Overheating is also a possibility, especially for alkylation reactors and distillation columns;

- Mechanical fatigue and shock in any equipment. Mechanical fatigue could result from age, vibration, or stress cycling, caused by pressure cycling, for example. Shock could occur from collisions with moving equipment such as cranes or other equipment in process or storage areas;

- Thermal fatigue and shock in alkylation reactors, heat exchangers, and distillation columns;

- Brittle fracture in any equipment, but especially in carbon steel equipment subjected to extensive corrosion where hydrogen embrittlement from hydrogen release by hydrogen fluoride attack may have occurred. Equipment

constructed of high alloys, especially high strength alloys selected to reduce the weight of major process equipment, might be especially sensitive where some corrosion has occurred or where severe operating conditions are encountered;

- Creep failure in equipment subjected to extreme operational upsets, especially excess temperatures. This can occur in equipment subjected to a fire; and

- All forms of corrosion. External corrosion from fugitive emissions of hydrogen fluoride could lead to equipment weakening. Stress corrosion cracking is also a possibility since this is characteristic of certain metals exposed to halogens.

3.4.3 Operational Causes

Operational causes of accidental releases are a result of incorrect operating and maintenance procedures or human errors (i.e., not following correct procedures). These causes include:

- Overfilled storage vessels;

- Improper process system operation;

- Errors in loading and unloading procedures;

- Inadequate maintenance in general, but especially on water removal unit operations, and pressure relief systems and other preventive and protective systems; and

- Lack of inspection and non-destructive testing of vessels and piping to detect corrosion weakening.

SECTION 4
HAZARD PREVENTION AND CONTROL

4.1 GENERAL CONSIDERATIONS

Prevention of accidental releases relies on a combination of technological, administrative, and operational practices that apply to the design, construction, and operation of facilities where hydrogen fluoride is stored and used. Considerations in these areas can be grouped as follows:

- Process design;
- Physical plant design;
- Operating and maintenance practices; and
- Protective systems.

In each of these areas, specific factors must be considered that could lead to a process upset or failure that could directly cause a release of hydrogen fluoride to the environment or result in an equipment failure that would then cause the release. At a minimum, equipment and procedures should be examined to ensure that they are in accordance with applicable codes, standards, and regulations. In addition, stricter equipment and procedural specifications should be in place if extra protection against a release is considered appropriate.

Release prevention is discussed in the following subsections; more detailed discussions will be found in the manual on control technologies, part of this manual series.

4.2 PROCESS DESIGN

Process design involves the fundamental characteristics of the processes which use hydrogen fluoride. Any discussion of how process design may be involved in accidental chemical releases must include an evaluation of how deviations from expected process design conditions could initiate a series of events that could result in an accidental release. The primary focus is on how the process is controlled in terms of the basic process chemistry, and on the variables of flow, pressure, temperature, composition, and quantity. Additional considerations may include mixing systems, fire protection, and process control instrumentation. Modifications to enhance process integrity may result from review of these factors and would involve changes in quantities of materials, process pressure and temperature conditions, the unit operations, sequence of operations, the process control strategies, and the instrumentation used.

Table 4-1 shows the relationship between some specific process design considerations and individual processes described in Section 3 of this manual. This does not mean that other factors should be ignored; nor does it mean that proper attention to just the considerations in the table ensures a safe system. The considerations listed, and perhaps others, must be properly addressed if a system is to be safe.

The most significant considerations are aimed at preventing overheating and overpressuring systems containing hydrogen fluoride. If hydrogen fluoride is fed from a storage vessel under its own vapor pressure, the primary means of overpressure would be from overheating. Where hydrogen fluoride might be fed by nitrogen padding of a storage vessel, or through pumps or compressors, overpressuring could occur without overheating. Equipment failure without overpressure is possible if corrosion has weakened process equipment. Temperature monitoring is important, not only because of a potential overpressure or equipment weakening due to overheating, but also because hydrogen fluoride's corrosiveness increases with temperature.

TABLE 4-1. SOME PROCESS DESIGN CONSIDERATIONS FOR PROCESSES INVOLVING HYDROGEN FLUORIDE

Process Design Consideration	Process or Unit Operation
Contamination (with water and sulfur especially)	Alkylation and chlorofluorocarbons, feed systems, storage
Flow control of hydrogen fluoride feed	All
Temperature sensing and heating media flow control	Chlorofluorocarbon reactors, distillation and stripping column reboilers
Temperature sensing and cooling medium flow control	Alkylation reactors, distillation and stripping column condensors
Adequate pressure relief	Storage tanks, reactors, distillation and stripping columns, heat exchangers
Mixing	Alkylation reactors
Corrosion monitoring	All, but especially recycle circuits
Temperature monitoring	Alkylation reactors, chloro-fluorocarbon reactors, alkylation and stripping column reboilers
Level sensing and control	Storage tanks, settlers in alkylation and chlorofluorocarbon processes

4.3 PHYSICAL PLANT DESIGN

Physical plant design considerations include equipment, siting and layout, and transfer/transport facilities. Vessels, piping and valves, process machinery, instrumentation, and factors such as location of systems and equipment must all be considered. The following subsections cover various aspects of physical plant design, beginning with a discussion of materials of construction.

4.3.1 Equipment

Materials of Construction--

The proper selection of materials of construction for hydrogen fluoride service is dictated by conditions which directly and indirectly affect corrosion. Temperature, pressure, moisture content, flow velocity, aeration, and impurities such as sulfur compounds are important considerations in determining the appropriate materials. Table 4-2 lists possible materials of construction for hydrogen fluoride service (18). The National Association of Corrosion Engineers (NACE) also provides detailed information concerning the materials of construction for hydrogen fluoride service (22).

For anhydrous hydrogen fluoride at temperatures up to 150°F, fully killed mild steel, steel deoxidized using silicon and/or aluminum, is generally used (e.g., ASTM A516, Grade 60 or 70). However, hydrogen blistering can occur if plates contain lamination defects. Reducing the sulfur content to a maximum level of 0.010% or using inclusion-shaped controlled steels helps to eliminate blistering. Another possible problem is hydrogen cracking of hardened steels. Base metals, welds, and heat affected zones should be limited to a hardness less than HRC 22 to avoid the problem (22). This includes the use of low hardness bolts such as ASTM A193 Grade B7M instead of B7 (22). For temperature greater than 150°F, nickel-copper Alloy 400 and nickel-chromium-molybdenum alloys are often used. However, nickel-copper alloys may stress corrosion crack if humid air is in contact with the acid or if substantial aeration in the process stream occurs.

TABLE 4-2. CHARACTERISTICS OF MATERIALS OF CONSTRUCTION IN HYDROGEN FLUORIDE AND HYDROFLUORIC ACID SERVICE

HYDROGEN FLUORIDE OR STRONG ACID (70% OR	DILUTE ACIDS (UNDER 70% HF) OVER)
Satisfactory	Satisfactory
Copper*	Monels**
Monels**	Copper*
Inconel	Yellow Brass*
Low Carbon Steel (to 150°F) Hastelloy	Nickel (over 10%, <212°F)
Alloys B, C D Nickel Ni-resist Carpenter	Lead (Chemical Grade <60%, to b.p.)
20 Durimet 20 Magnesium Chlorimet 2 & 3	Silver
Karbate (70%) Polyethylene Unplasticized	Carpenter 20
Polyvinyl Chloride Saran-Lined Steel Pipe	70-30 Copper Nickel Alloy
(for 70% <120°F) Fluorocarbons (TFE, CFE	Magnesium (<185°F)
& FEP) Platinum Molybdenum**	Hastelloy Alloys B,C&D
	Karbate
Unsatisfactory	Neoprene (<50%, <140°F)
	Unplasticized Polyvinyl Chloride
Yellow Brass	Rubber-Lined Steel (<60%, <180°F)
Lead	Butyl-Rubber-Lined Steel (<60%, <180°F)
High Silicon Iron Alloys	GR-S (<60%, <180°F)
Cast iron	Carbon-Filled Sulfur Cement
Aluminum	Saran-Lined Pipe
Stainless Steels	Polypropylene Vinylidene Fluorides
Tantalum	Fluorocarbons (TFE, CFE & FEP) Platinum
Titanium	
Zirconium	Unsatisfactory
Low Silver Brazing Alloys	
Rubber, Natural & Synthetic	Steel
Glass & Ceramics	Stainless Steels
Epoxies	Ni-resist
Asbestos	Cast iron
	High Silicon Iron Alloys
	Glass & Ceramics
	Aluminum
	Inconel (<10%, <170°F)
	Wood
	Tantalum
	Titanium
	Zirconium
	Asbestos

*SO_2 and air free.
**May be unsuitable under aerating conditions.

Note: This table does not include exceptions to satisfactory service due to temperature, concentration, velocity, etc. It is given here to provide a starting point for selecting materials, but a given materials acceptability for a certain application should be confirmed by other references before it is used.

Hydrofluoric acid solutions of concentrations greater than 70% can also be handled in fully-killed mild steel up to 100°F if the steel has a passivation film on the surface and if velocity through the equipment is less than 1.0 foot per second (8). The passivation iron fluoride film results from a reaction between the steel and the acid and provides a protection from further corrosion. When velocities are in excess of 1.0 foot per second, the passivation film is eroded (8). Copper and its alloys are not suitable where anhydrous hydrogen fluoride flows at high velocity. Materials of greater acid resistance must be used in such service.

For anhydrous hydrogen fluoride or concentrated hydrofluoric acid solutions (greater than 70%) systems, carbon steel pipe is commonly used. ASTM A53 seamless or A106, Grade A or B steel piping is often selected (8). For piping up to one inch, the pipe should be welded steel, and for sizes of greater diameter, the pipe should be seamless steel (18). The flanges commonly used are of ANSI Class[a] forged steel, raised face, welding neck, and ASTM A-105 or A-181, (18). For concentrations less than 70% hydrogen fluoride, piping is commonly lined with polypropylene, unplasticized polyvinylchloride, polyvinylidenechloride, polyvinylidinefluoride, or tetrafluoropolyethylene (TFE) to prevent corrosion (18). Materials which are not recommended include aluminum, titanium, tin, ordinary grey iron, malleable iron fittings, general purpose valves, and porcelain valves.

Gaskets constructed of nickel-copper alloy 400 and TFE are commonly used for hydrogen fluoride service. These materials are resistant to corrosion at all hydrogen fluoride concentration levels.

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[a]ANSI Class refers to pressure ratings at specified temperatures as set by the American National Standards Institute (ANSI). For a carbon steel flange, Class 150 means a 150 psig pressure rating at 500°F, and Class 300 means a 300 psig pressure rating at 850°F.

Bolts with adequate resistance to hydrogen stress corrosion cracking must be used in holding the flanges together. Alloy steel studs with heavy hex nuts are commonly used. Several types of bolts are often used in hydrogen fluoride service including: ASTM A-307, Grade B, mild steel; ASTM A-193, Grade B-7-M, alloy steel with maximum Rockwell C hardness of 22; ASTM A-193, Grade B-8, Class 2, 304 stainless steel with a maximum Rockwell C hardness of 34 (18). If a flange begins to leak, bolts are usually replaced immediately.

Hydrofluoric acid in concentrations less than 70% must be handled and stored in nonferrous materials. Since nickel-copper alloy 400 is resistant to hydrofluoric acid in almost the entire concentration range, it is commonly used for storage of hydrogen fluoride. In addition, nickel-chromium-iron alloys and nickel-chromium-molybdenum alloys do not show corrosion in 40-60% hydrofluoric acid up to 206.6°F (8).

Glass and silicate ceramics should never be used with hydrogen fluoride or hydrofluoric acid at any concentration.

Vessels--

A variety of storage and process vessels is used in hydrogen fluoride service. Examples include small storage cylinders, chemical reactors, separation columns, heat exchangers, and large storage tanks. Each type of vessel has certain specifications under various codes and standards which should be adhered to in design and fabrication.

Hydrogen fluoride storage vessels range in size from 150-lb pressure cylinders for small scale use up to several thousand ton pressurized spherical storage tanks used by producers. Pressurized storage tanks varying from 100-200 tons are typically used to store hydrogen fluoride for use in chemical processes. In addition, refrigerated tanks varying in size from 100-250 tons are also used for hydrogen fluoride storage. The shell of a refrigerated storage tank is covered by refrigeration coils and insulation. These coverings must be removed before the tank can be inspected for signs of external

corrosion or wear. The shell of a pressurized tank does not need to be covered, and thus the exterior surface can be easily inspected. For this reason, most producers of hydrogen fluoride prefer to use pressurized storage in place of refrigerated storage. The hazard associated with pressurized hydrogen fluoride is felt to be more than offset by the ability to regularly inspect the tank. Because the relatively large inventories contained in hydrogen fluoride storage vessels, they represent one of the most hazardous parts of a hydrogen fluoride process facility.

In general, anhydrous hydrogen fluoride and hydrofluoric acid storage tanks should be designed and built in accordance with the ASME Code for Unfired Pressure Vessels. Special considerations may be as discussed in the code for lethal materials, or even stricter standards may be appropriate.

As stated earlier, the usual material for hydrogen fluoride storage vessels is mild steel. Because of the potential release of hydrogen during corrosive attack by moist hydrogen fluoride, welding processes are usually carefully controlled to avoid heat-affected zone hardness which can lead to hydrogen stress cracking. Shielded arc welding with double butt-welded longitudinal seams and single butt-welded girth seams with seal welds on the inside are commonly used for vessels, including those in hydrogen fluoride service.

A minimum design pressure for these storage tanks is at least 50 psig working pressure, with a requirement that the tanks be tested at 1.5 times the working pressure before use. A minimum corrosion allowance of at least a 1/8 inch on both the shell and heads is typically added to the thickness specified by the ASME code for the specified design pressure.

Vessel nozzles are constructed of mild steel with ANSI Class 300 or greater forged steel weld neck flanges. Except for single, flanged, bottom clean-out drains, bottom outlet nozzles are not often used since there is a greater risk of losing the entire tank contents as the result of valve or line

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failure. Where they are used, nozzles are usually double valved as a precautionary measure. The following nozzles are usually specified for mounting on top of the tank (18):

- One 3- or 4-inch nozzle for insertion of a dip pipe for removal of hydrogen fluoride from the tank;
- Two 2-inch nozzles: one for filling the tank and the other for a pressure relief device; and
- Three 1-inch nozzles: one for a dry air supply to pad the hydrogen fluoride out, one for a vent to a caustic scrubber, and the last for a pressure gauge.

Specific release prevention considerations for vessels include: overpressure protection, temperature control, and corrosion prevention. Relief devices are not usually provided for 150-pound cylinders. These cylinders are built to withstand very high pressures and must be kept from fire exposure, contamination, and mechanical damage. Larger vessels are usually equipped with pressure relief valves, as are tank trucks and rail cars. Process vessels are usually protected by pressure relief valves and/or rupture discs. Since hydrogen fluoride tends to corrode pressure relief valves, they are frequently separated from the chemical by a rupture disc. The pressure relief valve is set to relieve slightly above the design working pressure of the vessel, but well below the maximum allowable working pressure.

Pressure relief valves and rupture discs are designed to prevent explosion by allowing a controlled release of overpressurized contents. These relief systems are usually sized for flashing liquid caused by:

- Fire exposure (NFPA 30),
- Thermal expansion,

- Internal reaction/decomposition, and
- Excess supply rates.

Relief piping must be sized for adequate flow. To avoid direct discharge to the atmosphere, an overflow tank might be provided for overpressured liquid. If it is possibile that causes other than liquid thermal expansion may lead to overpressure, or where there is no overflow receiver, the vessels should be relieved either to a point in the process which can handle the discharge flow, or to a gas absorption system.

The foundations and supports for vessels are important design considerations, especially for large storage vessels and tall equipment such as distillation columns. Supports for storage tanks containing hydrogen fluoride are usually concrete saddles. Tubular support legs are usually avoided. The supports must be protected from possible hydrofluoric acid contact since rapid corrosion can result from dilution of the acid with moisture in the air. Fugitive emissions of hydrogen fluoride can lead to significant external corrosion of supports and bolting. These supports should be protected by fugitive emissions control and regular maintenance of structural members. Surface coatings of mastics or polymers may also help retard external corrosion.

Cylinder storage of hydrogen fluoride is common where small to moderate quantities are required. A hood with forced ventilation is commonly used with hydrogen fluoride cylinders. Cylinder storage temperatures should not exceed 130°F and cylinders should be located away from sources of heat (19). Trap or check-valves are commonly inserted in transfer lines to prevent hazardous backflow into the cylinder. In addition, pressure-reducing regulators are used when connecting cylinders to lower pressure piping systems to prevent overpressure with leaks or rupture of downstream line (19). Air pressure is usually not used to transfer hydrogen fluoride from cylinders since corrosion resulting in the generation of hydrogen gas can occur. When pressure transfer (above the vapor pressure of hydrogen fluoride) is needed, nitrogen or other

inert gases are usually used. Cylinders also may be slightly heated using hot water. However, care must be taken to guard against overpressure. Cylinders are usually examined periodically for signs of valve or other leakage and external deterioration. Cylinders which have been stored for long periods of time are usually safely vented prior to use, since they may contain hydrogen gas. Complete details on cylinder storage are provided in hydrogen fluoride manufacturer's literature (19,20).

The alkylation and chlorofluorocarbon reactors represent possible sources of major releases since they contain a large portion of the anhydrous hydrofluoric acid used in their respective processes. These reactors must, therefore, be properly constructed of appropriate materials of construction.

The feed to the reactors must be dry since moisture accelerates the corrosion rate of materials used in construction (e.g., carbon steel). Provisions should be made for exclusion of moisture during any process shutdowns, or purging of the reactors at shutdown and before startups.

Since the alkylation reaction is exothermic, a heat-exchange-tube bundle is commonly used to cool the alkylation reactor contents. Water is the cooling medium. This equipment must be designed to prevent water leakage into the acid section of the reactor. Provisions must be made for corrective action to be taken if such leakage should occur. Common precautions include ensuring that the water pressure is lower than the process fluid pressure, and monitoring the cooling water for pH. If leakage should then occur, the acid would enter the water system and be detected by the pH monitoring.

A pressure relief system and a means of gas purging is also sometimes incorporated into the reactor designs since hydrogen gas may build up as a result of corrosion. All vents should be routed to a caustic scrubber.

Distillation and stripping columns present significant release hazards because they contain large amounts of hydrogen fluoride in pure form and have a heat input. The conditions under which this equipment operates (especially

the column reboilers and bottoms pumps) are severe and as a result these areas are potential sites for a release.

If cooling in a condenser is lost, overpressure may occur. Thus, it is necessary to use pressure relief valves to protect against leaks and ruptures which can result from overpressure. Relief protection is also necessary in the event of a fire to protect from overpressure. Likewise, loss of steam to the reboilers can result in underpressure in the column.

Columns used in hydrogen fluoride service must be constructed from the suitable materials mentioned in Section 4.3.1. The columns should be properly supported, taking into consideration expansion and contraction as a result of temperature changes, corrosion, and possible wind loadings.

Piping--

As with hydrogen fluoride vessels, hydrogen fluoride pipework design must reflect the pressure, temperature, and corrosion concerns associated with use of the chemical. Careful attention must be paid to pipework and associated fittings since failures of this type of equipment are major causes of accidental releases of chemicals. Regardless of the physical state of the hydrogen fluoride, there are some general guidelines for hydrogen fluoride piping systems. The first is simplicity of design; the number of joints and connections should be minimized. In addition to being securely supported, pipes should be sloped, with drainage at the low points. Piping should be constructed to allow room for thermal expansion of the pipe and should be protected from exposure to fire and high temperatures. Placement of valves should ensure isolation of leaking pipes and equipment.

A chief concern in liquid hydrogen fluoride lines is overpressure due to thermal expansion of the chemical or pressure pulses caused by rapid valve closure. These pressures can be sufficient to rupture the pipe. Where applicable, an expansion chamber, such as the one shown in Figure 4-1, may be installed to prevent such a rupture. An expansion chamber device typically consists of a rupture disc and a receiver chamber which can hold about 20-30%

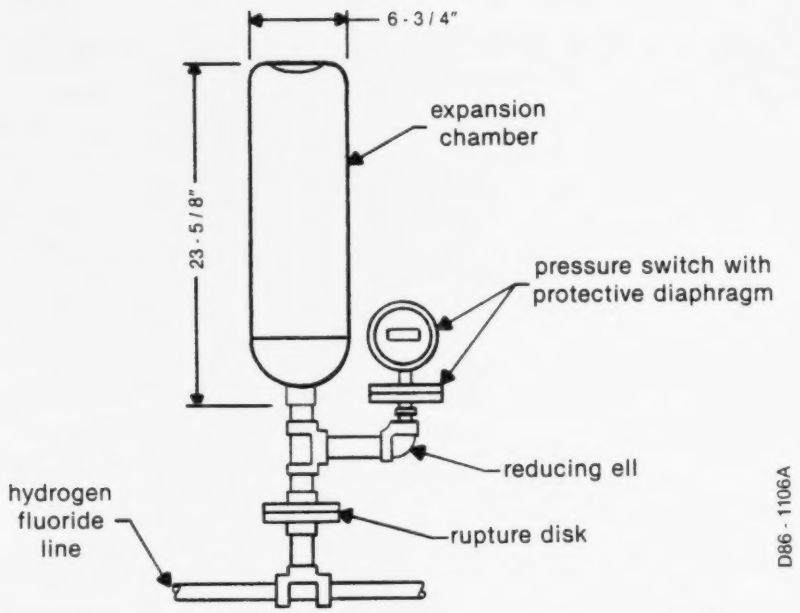


Figure 4-1. Concept of a liquid hydrogen fluoride expansion chamber.

Source: Adapted from Reference 23.

of the protected line's capacity. The chamber is equipped with a pressure indicator or alarm switch set to function upon disk rupture. The chamber should be constructed in accordance with Section VIII of the ASME Code for Unfired Pressure Vessels (23).

Another concern in liquid hydrogen fluoride systems is low temperature toughness. Material selection must take this into account and should be resistant to brittle fracture over the entire range of process conditions.

The correct design and use of pipe supports is essential to reducing overstress and vibration which could lead to piping failure. The supports should be designed to handle the load associated with the pipe, operating and testing medium, insulation, and other equipment. Factors that must be considered include thermal expansion and contraction, vibrations caused by pumping and fluid flow, bending moments as a result of overpressure in the pipe, and external loads such as winds or ice accumulation.

Piping networks are usually pressure tested at a minimum, to meet the requirements specified by ANSI code B31.3 (22). If a gas is used, it must be dry to prevent corrosion and resulting hydrogen gas formation. If water is used, the piping must be drained and blown dry before use.

As a result of the possible buildup of hydrogen gas from corrosive effects and the relatively low boiling point of hydrogen fluoride, rupture caused by hydrostatic pressure is possible. Protection against this is commonly achieved by installing a pressure relief valve, rupture disk, or a suitably designed, operated, and maintained expansion chamber (17).

All piping should be situated away from fire and fire hazards since the presence of hydrogen gas could trigger an explosion. If possible, piping carrying hydrogen fluoride should not be routed near other processes or piping networks that might present an external threat (e.g., piping carrying highly corrosive materials, high pressure processes). Pipe flanges should be

situated to minimize potential hazards from drips and small leaks since these could cause rapid external corrosion. In addition, the piping network should be protected from possible impact and other structural damage.

Valves in hydrogen fluoride service are discussed in a number of references (8,17,18,24). Several types of valves, including gate, globe, ball, relief, excess flow, and check configurations are used in hydrogen fluoride-containing systems. Valves of all sizes and for all pressure ranges used in hydrogen fluoride alkylation processes must be approved by one of the major hydrofluoric acid alkylation process licensers (i.e., U.O.P., Phillips Petroleum and Chevron) before being used (24).

Nickel-copper Alloy 400 is commonly used for all valve trim parts (i.e., seats, disks and stems) because of its resistance to the corrosive properties of hydrofluoric acid. A problem with valve trim materials is that they have thermal expansion coefficients which exceed those of cast or forged carbon steel and as a result often become distorted, causing leaks. Often this is solved by either closing the valve more tightly or inserting an acid compatible ring either in or alongside the trim material in the seat or disk. For anhydrous hydrogen fluoride, the valve bodies can be cast steel. For hydrofluoric acid (<70% concentration) nickel-copper alloy 400 valve bodies are often used.

Hydrofluoric acid will react with carbon steel and, to a lesser extent, with copper-nickel alloys that contain small amounts of iron to form ferric fluoride. Thus, hydrogen fluoride valves must have appropriate clearances at critical interfaces, such as wedge/body guides and stem back-seat bushings, to prevent the valves from becoming inoperable from ferric fluoride deposits.

Check valves are a primary means of preventing undesired back or reverse flows. They are typically mounted vertically on hydrogen fluoride storage tanks so that forward flow is required to lift and open them. Such valves can prevent undesired materials from entering hydrogen fluoride-containing equipment and also prevent possible explosions as a result of backups into tanks.

Check valves are also used widely on the pump discharges to prevent undesired backflow which could render a pump inoperable and eventually result in a hazardous release. Nickel-copper alloy ball check valves are commonly used in hydrogen fluoride service. Dual check valves in series are commonly used in sensitive/severe service areas. A power operated control valve with suitable instrumentation may be used as a substitute for a check valve.

Pressure relief devices should be installed on all hydrogen fluoride-containing vessels where the chemical can be blocked in. Such devices are set to relieve at a pressure approximately equal to the design pressure (which is greater than the normal operating pressure) for each specific piece of equipment. Where fires are likely, in alkylation units for example, the relief system should also be designed for fire relief, which tends to require a larger pressure relief capacity.

Process Machinery--

Process machinery refers to rotating or reciprocating equipment that may be used in the transfer or processing of hydrogen fluoride or hydrofluoric acid. This includes pumps and compressors that may be used to move liquid or gaseous hydrogen fluoride where gas pressure padding is insufficient or inappropriate.

Pumps--Many of the concerns and considerations for hydrogen fluoride piping and valves also apply to pumps. To assure that a given pump is suitable for a hydrogen fluoride service application, the system designer should obtain information from the pump manufacturer certifying that the pump will perform properly in this application.

Pumps should be constructed with materials resistant to hydrogen fluoride at operating temperatures and pressures. They should be installed dry and oil-free. It is especially important that their design not allow hydrogen fluoride or lubricating oil to enter seal chambers where they may contact one other. Net positive suction head (NPSH) considerations are especially

important for hydrogen fluoride since pumping the liquid near its boiling point may be common (hydrogen fluoride boils at near ambient conditions). The pump's supply tank should have high and low level alarms; the pump should be interlocked to shut off at low supply level or low discharge pressure. External pumps should be situated inside a diked area, and should be accessible in the event of a tank leak.

The type of pump selected depends on pumping requirements and operating conditions. Centrifugal, rotary, positive displacement, and sealess pumps are used to pump hydrogen fluoride. The pumps used should be constructed of suitable materials such as carbon steel, nickel-chromium-molybdenum and nickel-copper alloys which are resistant to hydrogen fluoride corrosion. These pumps are subject to shaft seal leakage, so seal rings made of polyvinylidenefluoride, nickel-chromium-molybdenum alloy and nickel-copper Alloy 400 are often used to eliminate this problem. Close-fitting moving parts should not be constructed of steel since the ferric fluoride film produced by the corrosion of steel can cause the parts to freeze up. In addition, Type 400 stainless steels, cast iron, and hardened steels should never be used.

In some situations, the potential for seal leakage rules out the use of standard rotating shaft seals. One solution is to use pump types that isolate the seals from the process stream. The seals are typically cartridge canister double type (25). The buffer fluid between the mechanical seals is commonly light oil. Another solution is to use pump types that eliminate shaft seals altogether such as canned-motor pumps, vertical submersible pumps, magnetically coupled pumps and diaphragm pumps (4,17).

Canned motor pumps are centrifugal units in which the motor housing is interconnected with the pump casing. Here, the process liquid actually serves as the bearing lubricant. An alternative concept is the vertical pump often used on storage tanks. These pumps consist of a submerged impeller housing connected by an extended drive shaft to the motor. The advantages of this

arrangement are that the shaft seal is above the maximum liquid level (and is therefore not wetted by the pumped liquid) and the pump is self priming because the liquid level is above the impeller.

Pumps using stuffing boxes and packing should be provided with double-packed seal chambers designed to prevent hydrogen fluoride from contacting any reactive material. These chambers can be purged with an appropriate inert fluid such as dry and oil-free nitrogen, or a suitable seal liquid. The seal gas pressure should exceed the tank pressure by an appropriate margin. A seal fluid back-up system should be considered (25).

Magnetically-coupled pumps replace the drive shaft with a rotating magnetic field as the pump-motor coupling device. Diaphragm pumps are positive displacement units in which a reciprocating flexible diaphragm drives the fluid. This arrangement eliminates exposure of packing and seals to the pumped liquid.

For metering service, diaphragm pumps are commonly used. The main advantage of this type of pump is that none of the packing and seals are exposed to the pumped liquid. However, a major consideration in the application of such pumps is that at some point, diaphragm failure will probably occur. Such a failure could lead to a release. These pumps may have a pressure relief valve on the outlet, bypassing to the suction.

Improper operation of pumps caused by cavitation, running dry, and deadheading can cause damage and failure of pumps. Cavitation can be a problem in pumping because of the low boiling point of hydrogen fluoride and the tendency to vaporize easily. If cavitation is allowed to occur, pitting and eventual serious damage to the impeller can result. Running a pump dry as a result of loss of head in a feed tank, for example, can seriously damage the pump. Finally, pumping against a closed valve can have serious ramifications. A pump bypass or kick-back are useful in avoiding such an occurrence. Failure of a pump, for whatever reason, can eventually lead to a hazardous release.

Centrifugal pumps often have a recycle loop back to the feed container that prevents overheating if the pump is deadheaded. This is an important consideration in hydrogen fluoride systems since hydrogen fluoride corrosiveness increases rapidly with increasing temperature. Deadheading is also a concern with positive displacement pumps. To prevent rupture, positive displacement pumps commonly have a pressure relief valve that bypasses to the pump suction. Because of the probability of eventual diaphragm failure, the use of diaphragm pumps should be carefully considered in view of this hazard potential.

Pumps are not always necessary; in many circumstances, liquid hydrogen fluoride is moved by pressure padding. With hydrogen fluoride cylinders and ton-containers, the liquid may be displaced from the vessel by the force of hydrogen fluoride vapor pressure. As discussed earlier, this process is temperature dependent. With other types of vessels, an inert gas such as dry nitrogen may be used to force liquid from the tank. Padding system designs must reflect the operating conditions and limitations (e.g., required flow rate) and therefore must be custom designed for a process.

Compressors--Reciprocating, centrifugal, liquid-ring rotary, and non-lubricated screw compressors are used with hydrogen fluoride. Details of such compressors used with hydrogen fluoride are discussed in the technical literature (4,25).

Like pumps, compressors have the potential for heat buildup and shaft seal leakage. Heat sources in a compressor include the heat of compression as well as the heat generated through mechanical friction. Heat buildup in hydrogen fluoride compressors is a particular concern because hydrogen fluoride's corrosion increases with increasing temperature. Most multistaged compressors can be equipped with intercoolers which limit heat buildup and increase compressor efficiency by reducing the volume of gas going to the next compression stage. Both air and water cooling are used, but water systems

must be designed to prevent leakage and contact of water with hydrogen fluoride.

While it is often possible to avoid using rotary shaft seals with hydrogen fluoride pumps, compressors in hydrogen fluoride service usually require special seals such as double labyrinth seals. These seals have a series of interlocking touch points which, by creating many incremental pressure drops, reduce total leakage. Also, to further reduce leakage, dry air is injected into the seal. In the event of deadheading, a compressor discharge can have a pressure relief mechanism that vents to the compressor inlet or to a scrubber system. The former appears to be satisfactory for a short term downstream flow interruption. Where a sustained interruption might occur, relief to a scrubber system would be safer. Positive displacement compressors and pumps must always be equipped with overpressure relief as close to the discharge as possible (non-isolatable).

Miscellaneous Equipment--

Pressure Relief Devices--Information on specific relief valve types for hydrogen fluoride service is not readily available; however, some characteristics for chlorine service seem to apply to hydrogen fluoride service as well. For vessels, an acceptable relief valve is of angle body construction with a closed bonnet and a screwed cap over the adjusting screw. These valves are normally used in combination with a rupture disc or a breaking pin assembly. Typical valve construction materials include a cast carbon steel body; a nickel plated steel spring; and nickel-copper or nickel-chromium-molybdenum alloy nozzle, disc adjusting ring, nozzle ring, and spindle guide. The inlet flange should be ANSI Class 300 or greater and the outlet flange should be ANSI Class 150 or greater. Valves of this construction which also have Viton® "O" ring seat seals need not have a rupture disc or breaking pin. Other types of pressure relief devices are acceptable as long as they are constructed of materials suitable for hydrogen fluoride service and meet the general

requirements of the ASME boiler and Pressure Vessel Code, Section VIII, Division 1 (8,26).

Rupture discs are constructed of appropriate hydrogen fluoride-resistant materials. Impervious graphite rupture discs fragment on overpressure and therefore should not be used in conjunction with relief valves. Connections can be screwed, flanged or socket-welded for connections smaller than two inches. However, connections two inches or larger should be flanged or butt-welded. The flanges should be constructed of forged carbon steel and be rated in accordance with the associated piping system. Because operating pressures exceeding 70% of a disc's burst pressure may induce premature failure, a considerable margin should be allowed when sizing rupture discs. When it is possible to draw a vacuum on the disc, supports should be provided (17).

Instrumentation--Process instrumentation in hydrogen fluoride service often uses isolating diaphragms for corrosion protection. Pressure gauges, switches, or sensors commonly use a nickel-chromium-molybdenum alloy diaphragm, and may be filled with an inert fluid, such as chlorofluorocarbon specialty lubricants (18). Bourdon tube pressure gauges are not commonly used, but if they are they would require a corrosion resistant alloy for the tube. The pressure range for both types of pressure measurement devices is commonly twice the operating pressure (23).

Similar considerations apply to other instrumentation, such as temperature, flow, and level measurement devices. All instruments should be protected from external corrosion as well as from direct process corrosion.

Periodic source-by-source fugitive emission monitoring can help identify hydrogen fluoride leaks which, if left unrepaired, might promote corrosion and increase the likelihood of a larger release. Continuous area monitoring can help detect the presence of large leaks.

Level gauges or weight systems can be used to monitor tank contents.

4.3.2 Plant Siting and Layout

The siting and layout of a particular hydrogen fluoride facility is a complex issue that requires careful consideration of numerous factors, including: other processes in the area, the proximity of population centers, prevailing winds, local terrain, and potential natural external effects such as flooding. The rest of this subsection describes general considerations which might apply to siting and layout of hydrogen fluoride facilities.

Facilities and individual equipment items should be situated to reduce personnel exposure, both plant and public, in the event of a release. Since there are also other siting considerations, there may be trade-offs between this requirement and others in a process, some directly safety related. Siting should provide ready ingress or egress in the event of an emergency and yet also take advantage of barriers, either man-made or natural, that could reduce the hazards of releases. Large distances between inventories and sensitive receptors is desirable.

Layout refers to the placement and arrangement of equipment in the process facility. All anhydrous hydrogen fluoride and aqueous hydrofluoric acid storage and handling equipment should be located away from other potentially hazardous storage and handling facilities. Such equipment is usually located in concrete enclosures or pits surrounded by curbing or walls to prevent acid spills from contaminating surrounding areas and also to serve as a boundary for the restricted acid area. Concrete containment areas are often treated with polymeric sealers to increase the containment efficiency. The drain system from the containment area should be designed so that storm water is routed to wastewater treating. The system should be capable of directing spilled hydrogen fluoride to a high-capacity neutralization facility. Containment of hydrogen fluoride by berms of lime-containing rock has been suggested as a means of combined containment and passive neutralization. The effectiveness of these systems has not been determined.

Various techniques available for formally assessing a plant layout should be considered when planning high-hazard facilities (17).

General layout considerations include:

- Large inventories of hydrogen fluoride should be kept away from sources of fire or explosion hazard;

- Vehicular traffic should not go too near hydrogen fluoride process or storage areas if this can be avoided;

- Where such traffic is necessary, precautions should be taken to reduce the chances of vehicles colliding with equipment, especially pipe racks carrying hydrogen fluoride across or next to roadways;

- Preferably, hydrofluoric acid piping should not be located adjacent to other piping that is under high pressure or temperature, or that carries flammable materials; and

- Storage facilities should be segregated from the main process unless the hazards of pipe transport are felt to outweigh the hazard of the storage tank for site-specific cases.

Because heat increases the corrosiveness of hydrogen fluoride and causes thermal expansion of liquid hydrogen fluoride, measures should be taken to situate piping, storage vessels, and other hydrogen fluoride equipment so that they are less exposed to heat sources. Hot process piping, equipment, steam lines, and other sources of direct or radiant heat should be avoided or systems should be designed with heat induced corrosion and pressure increases explicitly taken into account. Storage should also be situated away from control rooms, offices, utilities, other hazardous storage, and laboratory

areas by distances similar to those specified for flammable materials (17). Special precautions should be taken to keep hydrogen fluoride storage vessels away from potential fire or explosion sources.

In the event of an emergency, there should be at least two means of access to the facility for emergency vehicles and crews. Storage vessel shut-off valves should be readily accessible. Containment for liquid storage tanks can be provided by diking. Dikes reduce evaporation while containing the liquid. It is also possible to equip a diked area to allow drainage to an underground containment sump, which should be vented to a scrubber system for safe discharge. A full containment system using a specially constructed building vented to a scrubber is another possible option. This type of secondary containment could be considered for large volume, liquid hydrogen fluoride storage tanks.

4.3.3 Transfer and Transport Facilities

Transfer and transport facilities where both road and rail tankers are loaded or unloaded are likely accident areas because of vehicle movement and the intermittent nature of the operations. Therefore, special attention should be given to the design of these facilities.

As mentioned in the previous section, tank car and tank truck facilities should be located away from sources of heat, fire, and explosion. Equipment in these areas should also be protected from impact by vehicles and other moving equipment. These tank vehicles should be securely moored during transfer operations; an interlocked barrier system is commonly used. Sufficient space should be available to avoid congestion of vehicles or personnel during loading and unloading operations. Vehicles, especially trucks, should be able to move into and out of the area without reversing. High curbs around transfer areas and barriers around equipment should be provided to protect equipment from vehicle collisions.

When possible, the transfer of hydrogen fluoride should be made with fixed rigid piping. In situations that require flexible hoses or tubes, precautions must be taken to ensure sound connections. Avoiding cross contamination of chemical materials is also a key concern.

4.4 PROTECTION TECHNOLOGIES

This subsection describes two types of protection technologies, enclosures and scrubbers, for containment and neutralization.

4.4.1 Enclosures

Enclosures refer to containment structures that capture any hydrogen fluoride spilled or vented from storage or process equipment, thereby preventing immediate discharge of the chemical to the environment. The enclosures contain the spilled liquid or gas until it can be transferred to other containment, discharged at a controlled rate that would not be injurious to people or to the environment, or transferred at a controlled rate to scrubbers for neutralization.

Specially designed enclosures for hydrogen fluoride storage or process equipment do not appear to be widely used. Toxic operations located in the open air have been mentioned in the literature (11). The desirability of using an enclosure depends partly on how often personnel must be involved with the equipment. One reason for not enclosing areas where toxic materials are used is to prevent the accumulation of toxic concentrations within enclosed areas. However, if the issue is protecting the community from accidental releases, then total enclosure may be appropriate. Enclosures should be equipped with continuous monitoring equipment and alarms. Alarms should sound whenever lethal or flammable concentrations are detected.

Care must be taken when an enclosure is built around pressurized equipment. It would not be practical to design an enclosure to withstand the

pressures associated with the sudden failure of a pressurized vessel. An enclosure would probably fail as a result of the pressure created from such a release and could create an additional hazard. In these situations, it may be determined that an enclosure is not appropriate. If an enclosure is built around pressurized equipment then it should be equipped with some type of explosion protection, such as rupture plates that are designed to fail before the entire structure fails.

The type of structures that appear to be suitable for hydrogen fluoride are concrete blocks, or concrete sheet buildings or bunkers. While hydrogen fluoride would attack these structures, they would serve long enough to contain any spilled or leaked material until it could be discharged through a scrubber. An enclosure would have a ventilation system designed to draw in air when the building is vented to a scrubber. The bottom section of the building used for stationary storage containers should be liquid tight to retain any liquid hydrogen fluoride that might be spilled. Buildings around rail tank cars used for storage do not easily lend themselves to effective liquid containment. However, containment could be accomplished if the floor of the building is excavated several feet below the track level while the tracks are supported at grade in the center.

While enclosures do not seem to be widely used for secondary containment of hydrofluoric acid spills or releases, they might be considered for areas near sensitive receptors.

4.4.2 Scrubbers

Scrubbers, a traditional method for absorbing toxic gases from process streams, can be used for the control of hydrogen fluoride releases from vents and pressure relief discharges, from process equipment, or from secondary containment enclosures.

Hydrogen fluoride discharges could be contacted with an aqueous scrubbing medium in any of several types of scrubbing devices. An alkaline solution is required to achieve effective absorption because absorption rates with water alone might require unreasonably high liquid-to-gas ratios. However, water scrubbing could be used if an alkaline solution were not available. A typical alkaline solution for an emergency scrubber would be calcium hydroxide derived from slaked lime (i.e, lime water).

Types of scrubbers that might be appropriate include spray towers, packed bed scrubbers, and venturis. Other types of special designs might be suitable but complex internals subject to corrosion are not advisable. Typical absorption data for the various types of scrubbers used for hydrogen fluoride are presented in Table 4-3.

Whatever type of scrubber is selected, a complete system would include the scrubber itself, a liquid feed system, and reagent makeup equipment. If such a system is used as protection against emergency releases, consideration must be given to how it would be activated in time to respond to an emergency load. One approach used in some process facilities is to maintain a continuous circulation of scrubbing liquor through the system. For many facilities this would not be practical, and the scrubber system might be tied into a trip system to turn it on when it is needed. Venturi scrubbers have an advantage where the scrubbing system must be activated by a trip system. A venturi scrubber can create its own draw of vapor by the flow of the liquid. Thus a trip system need only turn on the flow of liquid to the scrubber rather than turn on the flow of liquid and start up a blower, as would be required with other types of scrubbing systems.

Another approach is the drowning tank, where the hydrogen fluoride vent is routed to the bottom of a large tank of uncirculating caustic. The drowning tank does not have the high contact efficiency of the other scrubber types, but it can provide substantial capacity on demand. However, the static

TABLE 4-3. TYPICAL HYDROGEN FLUORIDE ABSORPTION DATA

Type of Scrubbing Equipment	Scrubbing Medium	Gas Rate ($lb/hr/ft^2$)	Liquid Rate ($lb/hr/ft^2$)	Overall Mass Transfer Coefficient, K_Ga ($lb/mole/hr\text{-}ft^3\text{-}atm$)	Number of Transfer Unit, N_{OG}	Efficiency (%)
Crossflow Spray	Water	2,110	72	11	0.33	28
Crossflow Spray	Water	1,880	72	12	0.38	32
Crossflow Spray	Water	2,080	103	12	0.25	22
Crossflow Spray	Water	1,830	84	15	0.62	46
Crossflow Spray	Water	1,400	92	25	1.09	66
Crossflow Spray	Lime Water	2,050	105	35	1.50	77
Counterflow Spray	Water	2,000	800	9	5.85	99+
Parallel Flow Spray	Lime Water	13,800	3,800	51	2.58	92
Counterflow Spray	Water	2,000	380	4.3	2.5	92
Venturi:	Water	76,000[a]	42,000[a]	-	2.9	94
Venturi:	Water	70,000[a]	40,000-65,000[a]	-	2.0	86
Venturi:	Water	70,000[a]	40,000-65,000[a]			
Venturi:	Water	70,000[a]	40,000-65,000[a]	-	2.3	90
Venturi:	Water	70,000[a]	40,000-65,000[a]	-	3.0	95
Venturi:	Water	70,000[a]	40,000-65,000[a]	-	3.9	98
Venturi:	Water	70,000[a]	40,000-65,000[a]	-	2.3	90

[a]Based on throat cross-section.

Source: Adapted from Reference 27.

head associated with the drowning tank must be less than the required relief pressure for the system to operate.

4.5 MITIGATION TECHNOLOGIES

If, in spite of all precautions, a large release of anhydrous hydrogen fluoride occurs, the first priority is to rescue workers in the immediate vicinity of the accident and to evacuate persons from downwind areas. The source of the release should be determined, and the leak should be plugged to stop the flow if possible. The next primary concern becomes reducing the effects of the released chemical on the plant and the surrounding community. Reducing the consequences of an accidental release of a hazardous chemical is referred to as mitigation. Mitigation technologies include such measures as physical barriers, water sprays and fogs, and foams where applicable. The purpose of a mitigation technique is to divert, limit, or disperse the chemical that has been spilled or released to the atmosphere in order to reduce the atmospheric concentration and the area affected by the chemical. The mitigation technology chosen for a particular chemical depends on the specific properties of the chemical including its flammability, toxicity, reactivity, and those properties that determine its dispersion characteristics in the atmosphere.

If a release occurs from a pressurized liquid hydrogen fluoride storage tank above the boiling point, a quantity of liquid will immediately flash off as vapor, while the remaining liquid will be cooled to the normal boiling point of 67.1°F. Heat transfer from the air and ground will result in further vaporization of the released liquid. Since the hydrogen fluoride accidentally released from a refrigerated storage tank is already at or below its normal boiling point, a comparable quantity of vapor will not flash off, as with the pressurized release discussed above, but heat transfer from the environment will cause evaporation and the formation of a vapor cloud. It is therefore desirable to minimize the area available for heat transfer to a liquid spill which in turn will minimize the rate of evaporation. Mitigation technologies

used to reduce the rate of evaporation of a released liquified gas include secondary containment systems such as impounding basins, dikes, and enclosures.

4.5.1 Secondary Containment Systems

Specific types of secondary containment systems include excavated basins, natural basins, earth, steel, or concrete dikes, and high impounding walls. The type of containment system best suited for a particular storage tank or process depends on the risk associated with an accidental release from that location. The inventory of hydrogen fluoride and its proximity to other portions of the plant and to the community should be considered when selecting a secondary containment system, which should have the ability to contain spills with a minimum of damage to the facility and its surroundings and with minimum potential for escalation of the event.

Secondary containment systems for hydrogen fluoride storage facilities commonly consist of one of the following:

- An adequate drainage system underlying the storage vessels that terminates in a basin having a capacity as large as the largest tank served; and

- A diked area with a capacity as large as the largest tank served.

These measures are designed to prevent the accidental discharge of liquid hydrogen fluoride from spreading to uncontrolled areas.

The most common type of containment system is a low wall dike surrounding one or more storage tanks. Generally, to reduce risk, no more than three tanks are enclosed within one diked area. Dike heights usually range from three to twelve feet, depending on the area available to achieve the required

volumetric capacity. The dike walls should be liquid tight and able to withstand the hydrostatic pressure and temperature of a spill. Low wall dikes may be constructed of steel, concrete or earth. If earthen dikes are used, dike walls must be constructed and maintained to prevent leakage through the dike. Piping should be routed over dike walls, and penetrations through the walls should be avoided if possible. Vapor fences may be situated on top of the dikes to provide additional vapor storage capacity. If there is more than one tank in the diked area, the tanks should be situated on berms above the maximum liquid level attainable in the impoundment.

A low wall dike can effectively contain the liquid portion of an accidental release and keep the liquid from entering uncontrolled areas. By preventing the liquid from spreading, the low wall dike can reduce the surface area of the spill. Reducing the surface area will reduce the rate of evaporation. The low wall dike will partially protect the spill from wind; this can reduce the rate of evaporation. A dike with a vapor fence will provide extra protection from wind and will be even more effective at reducing the rate of evaporation.

A dike also creates the potential for hydrogen fluoride and trapped water to mix in the dike, which may accelerate the rate of evaporation and form highly corrosive hydrofluoric acid. If materials that would react violently with hydrogen fluoride are stored within the same diked area then the dike will increase the potential for mixing the materials in the event of a simultaneous leak. A dike also limits access to the tank during a spill.

A remote neutralization basin may be suitable for storage systems where more than one tank is served and a relatively large site is available. The flow from a hydrogen fluoride spill is directed to the basin by dikes and channels under the storage tanks, which are designed to minimize exposure of the liquid to other tanks and surrounding facilities. In the basin, the hydrogen fluoride is mixed with lime to form an insoluble fluoride sludge which can be hauled away for disposal (28). The lime could be stored in the

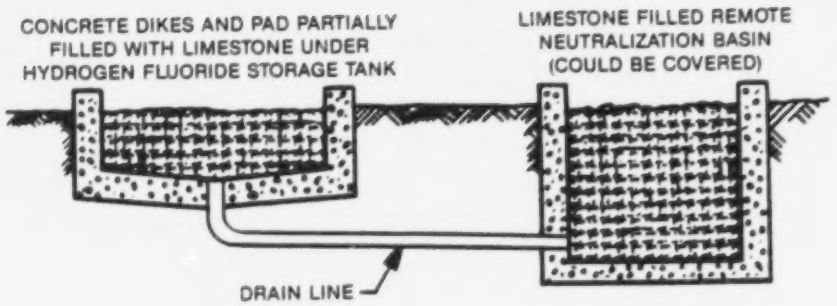
basin either as a premixed slurry or as solid limestone. Figure 4-2 illustrates two potential layouts for a remote neutralization basin. Because of hydrogen fluoride's high vapor pressure, the trenches that lead to the remote neutralization basin should be covered to reduce the rate of evaporation. Additionally, the neutralization basin should be located near the tank area to minimize the amount of hydrogen fluoride that evaporates as it travels to the basin. The use of neutralization basins is not widely practiced and should be considered developmental technology.

This type of system has several advantages. The spilled liquid is removed from the immediate tank area. This allows access to the tank during the spill and reduces the probability that the spilled liquid will damage the tank, piping, electrical equipment, pumps or other equipment. In addition, a lime-containing basin will immediately neutralize the hydrogen fluoride and prevent its release to the atmosphere.

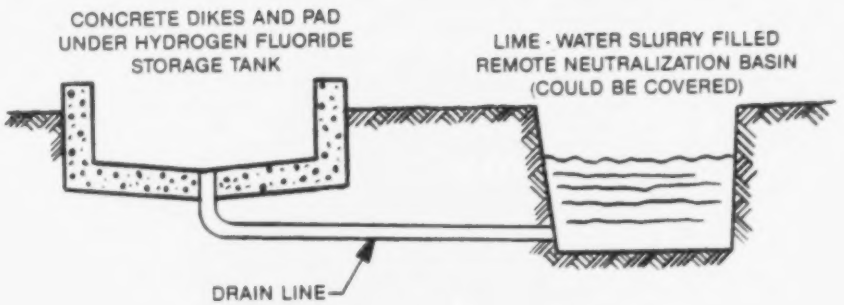
One limitation of a remote neutralization basin is that it does not completely reduce the impact of a gaseous release. Additionally, the reaction of lime with hydrogen fluoride is exothermic. The heat generated by the neutralization could result in an increase in the rate of evaporation of the liquid.

An alternative to a lime-filled basin is to allow the spilled liquid to flow into a covered, empty basin. The vapor from the basin could be directed to a scrubbing system. The advantage of this system is that the scrubber could be sized to accommodate the vapor generated from the spilled liquid. The disadvantages are the same as those mentioned in Section 4.4.2 where scrubbers as a protection technology are discussed.

Although few authorities for hydrogen fluoride facilities require them, high wall impoundments may be a good secondary containment choice for selected systems. Circumstances that may warrant their use include limited storage site area, the need to minimize vapor generation rates, and/or the tank must


CONCRETE DIKES AND PAD PARTIALLY FILLED WITH LIMESTONE UNDER HYDROGEN FLUORIDE STORAGE TANK
LIMESTONE FILLED REMOTE NEUTRALIZATION BASIN (COULD BE COVERED)
DRAIN LINE

LIMESTONE NEUTRALIZATION BASIN


CONCRETE DIKES AND PAD UNDER HYDROGEN FLUORIDE STORAGE TANK
LIME - WATER SLURRY FILLED REMOTE NEUTRALIZATION BASIN (COULD BE COVERED)
DRAIN LINE

D86 - 1099A

LIME WATER NEUTRALIZATION SYSTEM

Figure 4-2. Potential layouts for a remote neutralization basin system.

Source: Adapted from Reference 28.

be protected from external hazards. Maximum vapor generation rates will generally be lower for a high wall impoundment than for low wall dikes or remote impoundments because of the reduced surface contact area. These rates can be further reduced with the use of insulation on the wall and floor in the annular space. High impounding walls may be constructed of low temperature steel, reinforced concrete, or prestressed concrete. A weather shield may be provided between the tank and wall, with the annular space remaining open to the atmosphere. The available area surrounding the storage tank will dictate the minimum height of the wall. For high wall impoundments, the walls may be designed with a volumetric capacity greater than that of the tank to provide vapor containment. Increasing the height of the wall also raises the elevation of any released vapor.

One disadvantage of these dikes is that the high walls around a tank may hinder routine external observation. Furthermore, the closer the wall is to the tank, the more difficult it becomes to access the tank for inspection and maintenance. As with low wall dikes, piping should be routed over the wall if possible. The closeness of the wall to the tank may necessitate placement of the pump outside of the wall, in which case the outlet (suction) line will have to pass through the wall. In such a situation, a low dike encompassing the pipe penetration and pump may be provided, or a low dike may be placed around the entire wall.

Another type of secondary containment system is one which is structurally integrated with the primary system to form a vapor tight enclosure around the primary container. Many types of arrangements are possible. A double-walled tank is an example of such an enclosure. These systems may be considered where protection of the primary container and containment of vapor for events not involving foundation or wall penetration failure are of greatest concern. Drawbacks of an integrated system are the greater complexity of the structure, the difficulty of access to certain components, and the fact that complete vapor containment cannot be guaranteed for all potential events.

Provision should be made for drainage of rainwater from diked areas. This will involve the use of sumps and separate drainage pumps, since direct drainage to stormwater sewers would presumably allow any spilled hydrogen fluoride to follow the same route. Alternately, a sloped rain hood may be used over the diked area that could also serve to direct the rising vapors to a single release point (29). The ground within the enclosure should be graded to cause the spilled liquid to accumulate at one side or in one corner. This will help to decrease the area of ground which is exposed to the liquid and from which it may gain heat. In areas where it is critical to minimize vapor generation, surface insulation may be used in the diked area to further reduce heat transfer from the environment to the spilled liquid. The floor of an impoundment should be sealed with a clay blanket to prevent the hydrogen fluoride from seeping into the ground; percolation into the ground causes the ground to cool more quickly, increasing the vapor generation rate. Absorption of the hydrogen fluoride into water in the soil would also release additional heat.

4.5.2 Flotation Devices and Foams

Other possible means of reducing the surface area of spilled hazardous chemicals include placing impermeable flotation devices on the surface, dilution with water, and applying water-based foam. However, where hydrogen fluoride releases are concerned, neither of these are satisfactory.

Placing an impermeable flotation device over a spilled chemical is a direct approach for containing toxic vapors with nearly 100 percent efficiency. However, such devices must be acquired and stored until needed. In addition, deploymnet may be difficult in all but small spills.

Although such devices are potentially effective, no systems are currently available for use in mitigating hydrogen fluoride spills. The primary deterent to their use is the cost associated with material and disposal equipment. Such a system would require the dispersal of a minimum of 280 particles per

square foot of spill material (30). Based on 1986 prices, material costs would be approximately $100 per square foot, with dispersal equipment costs running 100 times the cost (30).

The use of foams in vapor hazard control has been demonstrated for a broad range of volatile chemicals. However, no foam systems are currently available for use with hydrogen fluoride. Results of a laboratory test program conducted by the Mine Safety Applicance (MSA) Research Corporation (31) to evaluate the applicability and effectiveness of various foams for various hazardous chemicals, including hydrogen fluoride, showed that because of the extremely high heat of solution, hydrogen fluoride boils and fumes violently upon application of foam.

Finally, diluting a hydrogen fluoride spill with water will result in highly corrosive hydrofluoric acid. Also, because of the high heat of solution, the addition of pure water results in violent boil-off of hydrogen fluoride and a dispersal of corrosive acid. Thus, water should not be used on a pool of hydrogen fluoride.

One alternative for hydrogen fluoride spills is to spread soda ash on the spill or use a strong soda ash solution to act as a neutralizing agent and prevent the release of toxic hydrogen fluoride vapors. This method would be appropriate for uncontained spills where the pool is shallow. This method would not be appropriate for deep pools, since the heat generated by the neutralization would probably result in violent boil-off of the hydrogen fluoride.

Another alternative for retarding evaporation of liquid hydrogen fluoride is to use a paraffin-base oil. A test program using several agents was conducted by Union Carbide Corporation (32). The results showed that certain varieties of oil spread over the surface and effectively sealed the vapors without being destroyed. Any oil used must have a high enough flash point to

prevent a secondary fire hazard from resulting. This method would not be appropriate for deep pools of hydrogen fluoride.

4.5.3 Mitigation Techniques for Hydrogen Fluoride Vapor

The extent to which the escaped hydrogen fluoride vapor can be removed or dispersed in a timely manner will be a function of the quantity of vapor released, the ambient conditions, and the physical characteristics of the vapor cloud. The behavior and characteristics of the hydrogen fluoride cloud will depend on a number of factors, including the physical state of the hydrogen fluoride before its release, the location of the release, and the atmospheric and environmental conditions. Many possibilities exist concerning the shape and motion of the vapor cloud, and a number of predictive models of dispersion have been developed. As a result of the higher specific gravity of pure hydrogen fluoride, large accidental releases of hydrogen fluoride will often result in the formation of hydrogen fluoride-air mixtures which are denser than the surrounding atmosphere. This type of vapor cloud is especially hazardous, because it will spread laterally and remain close to the ground.

One means of dispersing as well as removing toxic vapor from the air is with the use of water sprays or fogs. However, dilution of hydrogen fluoride with water results in the formation of highly corrosive hydrofluoric acid and presents an additional health hazard to plant personnel as well as corrosion problems for machinery and equipment. In addition, to be effective, an impractically large volume of water would have to be used, although it may be beneficial in controlling relatively small releases where the principal hazard is to plant personnel (33). An alternative is to use a mild aqueous alkaline spray system such as an ammonia-injected water spray system that would act as a neutralizing agent for the acid. Although such systems do not appear to be widely used for the mitigation of hydrogen fluoride vapors, they are used for other toxic chemicals of a similar nature (34).

The spray medium is typically applied to the vapor cloud by means of hand-held hoses and/or stationary water-spray barriers. Important factors relating to the effectiveness of spray systems are the distance of the nozzles from the point of release, the spray pattern, nozzle flow rate, pressure, and nozzle rotation. If spray systems are used to mitigate hydrogen fluoride vapors from a diked area containing spilled liquid hydrogen fluoride, great care must be taken not to direct water into the liquid hydrogen fluoride itself.

Several techniques have also been developed to effectively disperse toxic vapor resulting from major leaks in piping and equipment. One such technique has been developed by Beresford (35). Although such a system has not been used for the mitigation of hydrogen fluoride vapor, they have been effectively used for other toxic chemicals of similar nature (35). In addition, such techniques are not applicable to catastrophic failures of equipment.

The method consists of coarse water sprays discharging upwards from flat fan sprays and wide-angled spray monitors arranged so that a vent or chimney effect is created to completely surround the toxic vapor. Results have shown that the high velocity water droplets induce large volumes of air at ground level as the water discharges upwards (35). The air is caused to move upwards through the chimney formed by the sprays. As the air moves over the ground, the heavier-than-air toxic gas is diluted and pushed up and out of the top of the chimney, where it dispenses safely. Design details are presented in Beresford (35). Both types of spray methods are incorporated into the design since the flat-fan sprays effectively stop the lateral spread of vapor and the monitors provide the required air movement for dilution and dispersal.

A vapor cloud can also be dispersed with large fans or blowers that direct the vapor away from populated or other sensitive areas (36). However, this method would only be feasible in very calm weather and in sheltered areas; it would not be effective in any wind and would be difficult to control

if the release occupied a large open area. A large, mechanical blower would also be required, which lowers the reliability of this mitigation technique.

In general, techniques used to disperse or control vapor emissions should emphasize simplicity and reliability. In addition to the mitigation techniques discussed above, physical barriers such as buildings and rows of trees will help to contain the vapor cloud and control its movement.

4.6 OPERATION AND MAINTENANCE PRACTICES

Accidental releases of toxic materials result not only from deficiencies of design but also from deficiencies of operation. Thus safe operation of plants using hydrogen fluoride and hydrofluoric acid requires competent and experienced managers and staff in addition to a well considered and fully understood system of work.

Employees should be trained about the important aspects of handling hydrogen fluoride including: the proper means of handling and storing, hazards resulting from improper use and handling, prevention of spills, cleanup procedures, maintenance procedures and emergency procedures. Well defined and planned practices and procedures, including periodic drills, can minimize the possibility of a hazardous release and can also reduce the magnitude of an accidental release.

Proper maintenance and modification programs should be incorporated into plant design and operation to prevent possible hazardous releases of toxic material. Maintenance and modification work on hydrogen fluoride handling and storage equipment is usually kept to a minimum during operation.

Maintenance practices in processes where hydrogen fluoride is used can include pH readings of cooling water and condensate, commonly taken several times a day, to detect internal leaks and analysis of hydrogen fluoride for water several times a week to prevent corrosion (24).

4.7 CONTROL EFFECTIVENESS

It is difficult to quantify the control effectiveness of preventive and protective measures to reduce the probability and magnitude of accidental releases. Preventive measures, which may involve numerous combinations of process design, equipment design, and operational measures, are especially difficult to quantify because they reduce a probability rather than a physical quantity of a chemical release. Protective measures are more analogous to traditional pollution control technologies. Thus, they may be easier to quantify in terms of their efficiency in reducing a quantity of chemical that could be released.

Preventive measures reduce the probability of an accidental release by increasing the reliability of both process systems operations and the equipment. Control effectiveness can thus be expressed for both the qualitative improvements and the quantitative improvements through probabilities. Table 4-4 summarizes what appear to be some of the major design, equipment, and operational measures applicable to the primary hazards identified for the hydrogen fluoride applications in the SCAQMD. The items listed in Table 4-4 are for illustration only and do not necessarily represent a satisfactory control option for all cases. These control options appear to reduce the risk associated with an accidental release when viewed from a broad perspective. However, there are undoubtedly specific cases where these control options will not be appropriate. Each case must be evaluated individually.

4.8 ILLUSTRATIVE COST ESTIMATES FOR CONTROLS

This section presents cost estimates for different levels of control and for specific release prevention and protection measures that might be found in the SCAQMD for hydrogen fluoride storage and process facilities.

TABLE 4-4. EXAMPLES OF MAJOR PREVENTION AND PROTECTION MEASURES FOR HYDROGEN FLUORIDE RELEASES

Hazard Area	Prevention/Protection
Water contamination in hydrocarbon feeds to alkylation	Continuous moisture monitoring; Backflow prevention
Sulfur contamination in hydrocarbon feeds to alkylation	Continuous sulfur monitoring
Hydrogen fluoride flow control	Redundant flow control loops; Minimal overdesign of feed systems
Temperature sensing and cooling medium flow control	Redundant temperature sensors; Interlock flow switch to shut off HF feed on loss of cooling, with relief venting to emergency scrubber system
Temperature sensing and heating medium flow control	Redundant temperature sensors; Interlock flow switch to shut off HF feed on loss of heating, with relief venting to emergency scrubber system
Overpressure	Redundant pressure relief; adequate size; discharge not restricted
Mixing in alkylation reactors	Interlock HF and olefin feed shutoff with loss of mixing
Corrosion	Increased monitoring with more frequent inspections; use of pH sensing on cooling water and steam condensate loops; use of corrosion coupons[a]; visual inspections; non-destructive testing

(Continued)

TABLE 4-4 (Continued)

Hazard Area	Prevention/Protection
Reactor and reboiler temperatures	Redundant temperature sensing and alarms
Overfilling	Redundant independent level sensing, alarms and interlocks; training of operators
Atmosphere releases from relief discharges	Emergency vent scrubber system
Storage tank or line rupture	Enclosure vented to emergency scrubber system; diking; foams; dilution; neutralization; water sprays

[a] A piece of metal of known composition which is used to monitor corrosion rates by allowing it to reside in the corrosive environment and measuring the amount of corrosion as a function of time.

4.8.1 Prevention and Protection Measures

Preventive measures reduce the probability of an accidental release from a process or storage facility by increasing the reliability of both process systems operations and equipment. Along with an increase in the reliability of a system is an increase in the capital and annual costs associated with incorporating prevention and protection measures into a system. Table 4-5 presents costs for some of the major design, equipment, and operational measures applicable to the primary hazards identified in Table 4-4 for the hydrogen fluoride applications in the SCAQMD.

4.8.2 Levels of Control

The prevention of accidental releases relies on a combination of technological, administrative, and operational practices as they apply to the design, construction, and operation of facilities where hazardous chemicals are used and stored. At a minimum, equipment and procedures should be in accordance with applicable codes, standards, and regulations; however, additional measures can be taken to provide extra protection against an accidental release.

The levels of control concept provides a means of assigning costs to increased levels of prevention and protection. The minimum level is referred to as the "Baseline" system. This system consists of the elements required for normal safe operation and basic prevention of an accidental release of hazardous material.

The second level of control is "Level 1". "Level 1" includes the baseline system with added modifications, such as improved materials of construction, additional controls, and generally more extensive release prevention measures. The costs associated with this level are higher than the baseline system costs.

TABLE 4-5. ESTIMATED TYPICAL COSTS OF MAJOR PREVENTION AND PROTECTION MEASURES FOR HYDROGEN FLUORIDE RELEASES[a]

Prevention/Protection Measure	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Continuous moisture monitoring	7,500-10,000	900-1,300
Flow control loop	4,000-6,000	500-750
Temperature sensor	250-400	30-50
Pressure relief		
- relief valve	1,000-2,000	120-250
- rupture disk	1,000-1,200	120-150
Interlock system for flow shut-off	1,500-2,000	175-250
pH monitoring of cooling water	7,500-10,000	900-1,300
Alarm system	250-500	30-75
Level sensor		
- liquid level gauge	1,500-2,000	175-250
- load cell	10,000-15,000	1,300-1,900
Diking (based on a 10,000 gal. tank)		
- 3 ft. high	1,200-1,500	150-175
- top of tank height, 10 ft.	7,000-7,500	850-900
Increased corrosion inspection		200-400

[a]Based on a 10,000 gallon fixed hydrogen fluoride storage tank system and a 147,000 gal/day alkylation reactor system.

The third level of control is "Level 2". This system incorporates both the "Baseline" and "Level 1" systems with additional modifications designed specifically for the prevention of an accidental release, such as alarm and interlock systems. The extra accidental release prevention measures incorporated into "Level 2" are reflected in its cost, which is much higher than that of the baseline system.

When comparing the costs of the various levels of control, it is important to realize that higher costs do not necessarily imply improved safety. The measures applied must be applied correctly. Inappropriate modifications or add-ons may not make a system safer. Each added control option increases the complexity of a system. In some cases the hazards associated with the increased complexity may outweigh the benefits derived from the particular control option. Proper design and construction along with proper operational practices are needed to assure safe operation.

These estimates are for illustrative purposes only. It is doubtful that any specific installation would find all of the control options listed in these tables appropriate. An actual system is likely to incorporate some items from each of the levels of control and also some control options not listed here. The purpose of these estimates is to illustrate the relationship between cost and control, not to provide an equipment check list.

Two sets of cost estimates were prepared; one for a 42-ton fixed hydrogen fluoride storage tank system with 10,000 gal capacity and the other for a hydrogen fluoride alkylation reactor system for a 147,000 gal/day alkylate capacity plant. These systems are representative of storage and process facilities that might be found in the SCAQMD.

4.8.3 Cost Summaries

Table 4-6 summarizes the total capital and annual costs for each of the three levels of control for the hydrogen fluoride storage system and the

TABLE 4-6. SUMMARY COST ESTIMATES OF POTENTIAL LEVELS OF CONTROLS FOR HYDROGEN FLUORIDE STORAGE TANK AND ALKYLATION REACTOR

System	Level of Control	Total Capital Cost (1986 $)	Total Annual Cost (1986 $/yr)
HF Storage Tank; 42 ton Fixed HF Tank with 10,000 gal Capacity	Baseline	147,000	18,000
	Level No. 1	471,000	56,000
	Level No. 2	1,312,000	154,000
HF Alkylation Reactor at Typical Operating Conditions of 75-100°F and 80-115 psig with a 147,000 gal/day alkylate capacity	Baseline	2,425,000	332,000
	Level No. 1	4,172,000	544,000
	Level No. 2	4,453,000	579,000

hydrogen fluoride alkylation reactor system. The costs presented correspond to the systems described in Tables 4-7 and 4-8. Each of the level costs include the cost of the basic system plus any added controls. Specific cost information and breakdown for each level of control for both the storage and process facilities are presented in Tables 4-9 through 4-14.

4.8.4 Equipment Specifications and Detailed Costs

Equipment specifications and details of the capital cost estimates for the hydrogen fluoride storage and the hydrogen fluoride alkylation reactor systems are presented in Tables 4-15 through 4-22.

4.8.5 Methodology

Format for Presenting Cost Estimates--

Tables are provided for control schemes associated with storage and process facilities for hydrogen fluoride showing capital, operating, and total annual costs. The tables are broken down into subsections comprising vessels, piping and valves, process machinery, instrumentation, and procedures and practice. Presentation of the costs in this manner allows for easy comparison of specific items, different levels, and different systems.

Capital Cost--All capital costs presented in this report are shown as total fixed capital costs. Table 4-23 defines the cost elements comprising total fixed capital as it is used here.

The computation of total fixed capital, as shown in Table 4-23, begins with the total direct cost for the system under consideration. This total direct cost is the total direct installed cost of all capital equipment comprising the system. Depending on the specific equipment item involved, the direct capital cost was available or was derived from uninstalled equipment costs by computing costs of installation separately. To obtain the total

TABLE 4-7: EXAMPLE OF LEVELS OF CONTROL FOR HYDROGEN FLUORIDE STORAGE TANK[a]

Process: 42 ton fixed hydrogen fluoride storage tank
10,000 gal

Controls	Baseline	Level No. 1	Level No. 2
Flow:	Single check-valve on tank-process feed line.	Add second check valve.	Add a reduced-pressure device[b] with internal air gap and relief vent to containment tank or scrubber.
Temperature:	None	None	Add temperature indicator.
Pressure:	Single pressure relief valve, vent to atmosphere.	Add second relief valve. Vent to limited scrubber. Provide local pressure indicator.	Add rupture disks under relief valves. Provide local pressure indication on space between disk and valve.
Quantity:	Local level indicator.	Add independent remote level indicator.	Add level alarm. Add high-low level interlock shut-off for both inlet and outlet lines.
Location:	Away from traffic, and flammables, and other hazardous processes.	Away from traffic, flammables, and other hazardous processes.	Away from traffic, flammables, and other hazardous processes.
Materials of Construction:	Carbon steel.	Carbon steel with increased corrosion allowances. (1/8 inch)	Monel®.
Vessel:	Tank pressure specification 150 psig.	Tank pressure specification psig[c].	Tank pressure specification 375 psig[c].

(continued)

TABLE 4-7 (Continued)

Process: 42 ton fixed hydrogen fluoride storage tank
10,000 gal

Controls	Baseline	Level No. 1	Level No. 2
Piping:	Sch. 80 carbon steel.	Sch. 80 Saran®-lined carbon steel.	Sch. 80 Monel®.
Process Machinery:	Centrifugal pump, carbon steel, stuffing box.	Centrifugal pump, Monel® construction, double capacity mechanical seal.	Magnetically-coupled centrifugal pump, Monel® construction.
Enclosures:	None	Steel building.	Concrete building.
Diking:	None	3 ft high.	Top of tank height, 10 ft.
Scrubbers:	None	Water scrubber.	Alkaline scrubber.
Mitigation:	None	Water sprays.	Alkaline water sprays and barriers.

[a] The examples in this table are appropriate for many, but not all applications. This is only an exemplary system. Design must be suited to fit the service.

[b] A reduced pressure device is a modified double check valve.

[c] Note that tank pressure specification will be a function of maximum operating pressure. These values are chosen only as representative examples.

TABLE 4-8: EXAMPLE OF LEVELS OF CONTROL FOR HYDROGEN FLUORIDE ALKYLATION REACTOR[a]

Process: HF alkylation

Typical Operating Conditions: - Temperature: 75-100°F

- Pressure: 80-115 psig

Controls	Baseline	Level No. 1	Level No. 2
Process:	Dryers on feed lines.	Improved reactor design.	Use of interlock systems.
Temperature:	Provide local temperature control.	Add redundant temperature sensors and alarms. Add remote temperature indicator.	Add temperature switch and back-up cooling system.
Pressure:	Provide local pressure control. Single pressure relief valve. Vent to atmosphere.	Add redundant pressure sensors. Add second relief valve. Vent to limited scrubber. Add remote pressure indicator.	Add rupture disks under relief valves and provide local and remote pressure indicator on space between disk and valve.
Flow:	Provide local flow control on HF feed and cooling medium to reactor.	Add redundant flow control loops.	Add interlock flow switch to shut off HF feed on loss of cooling medium.
Quantity:	None	None	None
Mixing:	Provide adequate mixing.	Add agitation detection system.	Interlock HF and olefin feed shut off with loss of mixing.
Corrosion:	Visual inspection and pH monitoring of cooling medium.	Increased monitoring with increased inspections.	Add pH sensing on reactor cooling medium. Add corrosion coupons.

(continued)

TABLE 4-8 (Continued)

Process: HF alkylation

Typical Operating Conditions: - Temperature: 75-100°F

- Pressure: 80-115 psig

Controls	Baseline	Level No. 1	Level No. 2
Composition:	Dryers on feed lines.	Occasional moisture monitoring of feed.	Continuous moisture monitoring of feed.
Material of Construction:	Carbon-steel.	Carbon steel with added corrosion allowance.	Monel®.
Vessel:	Pressure specification: 150 psig.	Pressure specification: 200 psig.	Pressure specification: 300 psig.
Piping:	Sch. 80 carbon steel.	Sch. 80 Saran® lined carbon steel.	Sch. 80 Monel®.
Process Machinery:	Centrifugal pump, carbon steel construction, stuffing box.	Centrifugal pump, Monel® construction, double capacity mechanical seal.	Magnetically-coupled centrifugal pump, Monel® construction.
Protective Barrier:	None	Curbing around reactor/settler.	3 ft high retaining wall.
Enclosures:	None	Steel building.	Concrete building.
Scrubbers:	None	Water scrubbers.	Alkaline scrubbers.
Mitigation:	None	Water sprays.	Alkaline water sprays.

[a] The examples in this table are appropriate for many, but not all applications. This is only an exemplary system. Design must be suited to fit the specific service.

TABLE 4-9. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH BASELINE HYDROGEN FLUORIDE STORAGE SYSTEM

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
VESSELS:		
Storage Tank	131,000	15,000
PIPING AND VALVES:		
Pipework	2,300	270
Check Valve	280	30
Gate Valves (5)	1,700	200
Excess Flow Valves (2)	500	60
Angle Valves (2)	2,100	250
Relief Valve	2,000	240
PROCESS MACHINERY:		
Centrifugal Pump	4,000	460
INSTRUMENTATION:		
Pressure Gauges (4)	1,500	170
Liquid Level Gauge	1,500	170
PROCEDURES AND PRACTICES:		
Visual Tank Inspection (external)		15
Visual Tank Inspection (internal)		60
Relief Valve Inspection		15
Piping Inspection		300
Piping Maintenance		120
Valve Inspection		30
Valve Maintenance		350
TOTAL COSTS	147,000	18,000

TABLE 4-10. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH LEVEL 1 HYDROGEN FLUORIDE STORAGE SYSTEM

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
VESSELS:		
Storage Tank	187,000	22,000
Expansion Tanks (3)	6,500	760
PIPING AND VALVES:		
Pipework	6,200	720
Check Valve	560	65
Gate Valves (5)	1,700	200
Excess Flow Valves (2)	500	60
Angle Valves (2)	2,100	250
Relief Valves (2)	4,000	470
PROCESS MACHINERY:		
Centrifugal Pump	16,000	1,900
INSTRUMENTATION:		
Pressure Gauges (4)	1,500	175
Flow Indicator	3,700	430
Liquid Level Gauge	1,500	175
Remote Level Indicator	1,900	220
ENCLOSURES:		
Steel Building	10,000	1,200
SCRUBBERS:		
Water Scrubber	226,000	. 26,000

(Continued)

TABLE 4-10 (Continued)

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
DIKING:		
3 ft High Concrete Diking	1,400	160
PROCEDURES AND PRACTICES:		
Visual Tank Inspection (external)		15
Visual Tank Inspection (internal)		60
Relief Valve Inspection		30
Piping Inspection		300
Piping Maintenance		120
Valve Inspection		35
Valve Maintenance		400
TOTAL COSTS	471,000	56,000

TABLE 4-11. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH LEVEL 2 HYDROGEN FLUORIDE STORAGE SYSTEM

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
VESSELS:		
Storage Tank	932,000	109,000
Expansion Tanks (3)	6,500	760
PIPING AND VALVES:		
Pipework	9,200	1,100
Reduced Pressure Device	1,500	170
Gate Valves (5)	1,700	200
Excess Flow Valves (2)	500	60
Angle Valves (2)	2,100	250
Relief Valves (2)	4,000	470
Rupture Disks (2)	1,100	130
PROCESS MACHINERY:		
Magnetically-coupled Centrifugal Pump	19,000	2,200
INSTRUMENTATION:		
Temperature Indicator	2,200	260
Pressure Gauges (6)	2,200	260
Flow Indicator	3,700	430
Load Cell	16,000	1,900
Remote Level Indicator	1,900	220
Level Alarm	380	45
High-Low Level Shutoff	1,900	220
ENCLOSURES:		
Concrete Building	19,000	2,300

(Continued)

TABLE 4-11 (Continued)

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
SCRUBBERS:		
Alkaline Scrubber	280,000	33,000
DIKING:		
10 ft High Concrete Diking	7,600	500
PROCEDURES AND PRACTICES:		
External Tank Inspection		15
Internal Tank Inspection		60
Relief Valve Inspection		50
Piping Inspection		300
Piping Maintenance		120
Valve Inspection		35
Valve Maintenance		400
TOTAL COSTS	1,312,000	154,000

TABLE 4-12. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH BASELINE HYDROGEN FLUORIDE ALKYLATION REACTOR/SETTLER SYSTEM

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
EQUIPMENT:		
Vessels and Machinery:		
Reactor/Settler		
Feed Dryers (2)		
Centrifugal Pumps (3)		
Total Vessels and Machinery[a]	1,459,000	175,000
Piping and Valves:[a]	664,000	79,000
INSTRUMENTATION:[a]	302,000	36,000
Maintenance and Inspections:[a]		42,000
TOTAL COSTS	2,425,000	332,000

[a] Costs are based on using cost factors from Peters and Timmerhaus (37) and a total fixed capital cost of $10.06 million (1986 basis) (38) for a 147,000 gal/day alkylate capacity plant.

TABLE 4-13. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH LEVEL 1 HYDROGEN FLUORIDE ALKYLATION REACTOR/SETTLER SYSTEM

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
EQUIPMENT:		
Vessels and Machinery:		
Reactor/Settler		
Feed Dryers (2)		
Centrifugal Pumps (3)		
Total Vessels and Machinery[a]	2,646,000	318,000
Piping and Valves:[a]	943,000	114,000
Relief Valve	2,000	230
INSTRUMENTATION:[a]	302,000	36,000
Temperature Sensor	360	45
Temperature Alarm	360	45
Remote Temperature Indicator	1,800	220
Remote Pressure Indicator	1,800	220
Flow Control Loops (2)	11,000	1,300
Agitation Detection System and Alarm	1,800	220
DIKING:		
Curbing Around Reactor	1,200	150
SCRUBBER:		
Water Scrubber	260,000	31,000
MAINTENANCE AND INSPECTIONS:[a]		42,000
Relief Valve Inspection		15
TOTAL COSTS	4,172,000	544,000

[a] Costs are based on using cost factors from Peters and Timmerhaus (37) and a total fixed capital cost of $10.06 million (1986 basis) (38) for a 147,000 gal/day alkylate capacity plant.

TABLE 4-14. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH LEVEL 2 HYDROGEN FLUORIDE ALKYLATION REACTOR/SETTLER SYSTEM

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
EQUIPMENT:		
Vessels and Machinery:		
Reactor/Settler		
Feed Dryers (2)		
Centrifugal Pumps (3)		
Total Vessels and Machinery[a]	2,646,000	319,000
Piping and Valves:[a]	943,000	114,000
Relief Valves (2)	4,000	470
Rupture Disk	2,300	280
INSTRUMENTATION:[a]	302,000	36,000
Temperature Sensor	360	45
Temperature Alarm	360	45
Temperature Switch	540	65
Remote Temperature Indicator	1,800	220
Remote Pressure Indicator	1,800	220
Flow Control Loops (2)	11,000	1,300
Flow Interlock System	1,800	220
Agitation Detection System and Alarm	1,800	220
Mixing Interlock System	1,800	220
pH Monitoring System	9,000	1,100
Moisture Monitoring System	9,000	1,100
All Loops on Computer Control[b]	201,000	24,000
DIKING:		
3 ft High Retaining Wall	3,000	360
SCRUBBER:		
Alkaline Scrubber	312,000	38,000
MAINTENANCE AND INSPECTIONS:[a]		42,000
Relief Valve Inspection		25
TOTAL COSTS	4,453,000	579,000

[a]Costs are based on using cost factors from Peters and Timmerhaus (37) and a total fixed capital cost of $10.06 million (1986 basis) (38) for a 147,000 gal/day alkylate capacity plant.

[b] Computer Control costs are determined using cost estimating factors from Valle-Riestra (39).

TABLE 4-15. EQUIPMENT SPECIFICATIONS ASSOCIATED WITH HYDROGEN FLUORIDE STORAGE SYSTEM

Equipment Item	Equipment Specification	Reference
VESSELS:		
Storage Tank	Baseline: 10,000 gal. Carbon Steel Storage Tank, 150 psig	
	Level #1: 10,000 gal. Carbon Steel With 1/8 in. Corrosion Protection, 225 psig	
	Level #2: 10,000 gal. Monel® 375 psig	37,40,41, 42
Expansion Tank	Standard Carbon Steel Pressure Vessel With Rupture Disk and Pressure Gauge	37,40
PIPING AND VALVES:		
Pipework	Baseline: 1 in. Schedule 80 Carbon Steel	
	Level #1: 1 in. Schedule 80 Saran®-lined Carbon Steel	
	Level #2: 1 in. Schedule 80 Monel®	43
Check Valve	1 in. Vertical Lift Check Valve, Monel® Trim	40,44
Gate Valve	1 in. Screwed, Monel® Trim, Bolted Bonnet	37,40,44
Excess Flow	1 in. Standard Valve	40
Angle Valves	1 in. Carbon Steel, Monel® Trim	45
Relief Valves	1 in. x 2 in., Class 300 Inlet and Outlet Flange, Angle Body, Closed Bonnet With Screwed Cap, Carbon Steel Body, Monel® Trim	40
Reduced Pressure Device	Double Check Valve Type Device With Internal Air Gap and Relief Valve	37
Rupture Disk	1 in. Monel® Disk and Carbon Steel Holder	41,46,47
PROCESS MACHINERY:		
Centrifugal Pump	Baseline: Single Stage, Carbon Steel Construction, Stuffing Box, 100 gpm Capacity	
	Level #1: Single Stage, Monel® Construction, Double Mech. Seal	40,48
	Level #2: Monel® Construction, Magnetically-Coupled	40,48

(Continued)

TABLE 4-15 (Continued)

Equipment Item	Equipment Specification	Reference
INSTRUMENTATION:		
Pressure Gauge	Diaphragm Sealed, Hastelloy C Diaphragm, 0-1,000 psi	37,40,43
Liquid Level Gauge	Differential Pressure Type	37,43
Temperature Indicator	Thermocouple, Thermowall, Electronic Indicator	37,40,43
Flow Indicator	Differential Pressure Cell and Transmitter and Associated Flowmeter	37,43
Level Indicator	Differential Pressure Type Indicator	37,40,43
Load Cell	Electrical Load Cell	37,43,49
Level Alarm	Indicating and Audible Alarm	40,45,50
High-low Level Shutoff	Solenoid Valve, Switch, and Relay System	37,40,43, 45
ENCLOSURES:		
Building	Level #1: 26-Gauge Steel Walls and Roof, Door, Ventilation System Level #2: 10 in. Concrete Walls, 26-Gauge Steel Roof	45
SCRUBBERS:	Level #1: Spray Tower, Monel® Construction, Water Sprays, 6 ft. x 18 ft. Level #2: Spray Tower, Monel® Construction, Alkaline Sprays	51
DIKING:	Level #1: 6 in. Concrete Walls, 3 ft. High Level #2: 10 in. Concrete Walls, Top of Tank Height (10 ft.)	45

TABLE 4-16. DETAILS OF MATERIAL AND LABOR COSTS ASSOCIATED WITH BASELINE HYDROGEN FLUORIDE STORAGE SYSTEM

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
VESSELS:					
Storage Tank	61,000	27,000	88,000	31,000	131,000
PIPING AND VALVES:					
Pipework	550	1,000	1,550	540	2,300
Check Valve	160	30	190	60	280
Gate Valves (5)	1,000	150	1,150	400	1,700
Excess Flow Valves (2)	300	40	340	120	500
Angle Valves (2)	1,400	40	1,440	500	2,100
Relief Valve	1,300	50	1,350	470	2,000
PROCESS MACHINERY:					
Centrifugal Pump	1,900	800	2,700	940	4,000
INSTRUMENTATION:					
Pressure Gauges (4)	800	200	1,000	350	1,500
Liquid Level Gauge	800	200	1,000	350	1,500
TOTAL COSTS	69,000	30,000	99,000	35,000	147,000

TABLE 4-17. DETAILS OF MATERIAL AND LABOR COSTS ASSOCIATED WITH LEVEL 1 HYDROGEN FLUORIDE STORAGE SYSTEM

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
VESSELS:					
Storage Tank	87,000	39,000	126,000	44,000	187,000
Expansion Tanks (3)	3,500	880	4,380	1,500	6,500
PIPING AND VALVES:					
Pipework	3,300	860	4,160	1,500	6,200
Check Valves (2)	320	60	380	130	560
Gate Valves (5)	1,000	150	1,150	400	1,700
Excess Flow Valves (2)	300	40	340	120	500
Angle Valves (2)	1,400	40	1,440	500	2,100
Relief Valves (2)	2,600	100	2,700	950	4,000
PROCESS MACHINERY:					
Centrifugal Pump	7,900	3,400	11,300	3,900	16,000
INSTRUMENTATION:					
Pressure Gauges (4)	800	200	1,000	350	1,500
Flow Indicator	2,000	500	2,500	880	3,700
Liquid Level Gauge	800	200	1,000	350	1,500
Remote Level Indicator	1,000	250	1,250	440	1,900
ENCLOSURES:					
Steel Building	4,600	2,300	6,900	2,400	10,000
SCRUBBERS:					
Water Scrubber	105,000	47,000	152,000	53,000	226,000

(Continued)

TABLE 4-17 (Continued)

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
DIKING:					
3 ft High Concrete Diking	390	520	910	320	1,400
TOTAL COSTS	222,000	95,000	317,000	111,000	471,000

TABLE 4-18. DETAILS OF MATERIAL AND LABOR COSTS ASSOCIATED WITH LEVEL 2 HYDROGEN FLUORIDE STORAGE SYSTEM

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
VESSELS:					
Storage Tank	432,000	195,000	627,000	220,000	932,000
Expansion Tanks (3)	3,500	880	4,380	1,500	6,500
PIPING AND VALVES:					
Pipework	4,800	1,400	6,200	2,200	9,200
Reduced Pressure Device	800	200	1,000	350	1,500
Gate Valves (5)	1,000	150	1,150	400	1,700
Excess Flow Valves (2)	300	40	340	120	500
Angle Valves (2)	1,400	40	1,440	500	2,100
Relief Valves (2)	2,600	100	2,700	950	4,000
Rupture Disks (2)	650	80	730	260	1,100
PROCESS MACHINERY:					
Magnetically-Coupled Centrifugal Pump	9,000	3,900	12,900	4,500	19,000
INSTRUMENTATION:					
Temperature Indicator	1,200	300	1,500	530	2,220
Pressure Gauges (6)	1,200	300	1,500	530	2,200
Flow Indicator	2,000	500	2,500	880	3,700
Load Cell	8,400	2,100	10,500	3,700	16,000
Remote Level Indicator	1,000	250	1,250	440	1,900
Level Alarm	200	50	250	90	380
High-Low Level Shutoff	1,000	250	1,250	440	1,900
ENCLOSURES:					
Concrete Building	6,100	6,600	12,700	4,500	19,000

(Continued)

TABLE 4-18 (Continued)

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
SCRUBBERS:					
Alkaline Scrubber	130,000	59,000	189,000	66,000	280,000
DIKING:					
10 ft High Concrete Dike	2,200	2,900	5,100	1,800	7,600
TOTAL COSTS	609,000	274,000	884,000	310,000	1,312,000

TABLE 4-19. EQUIPMENT SPECIFICATIONS ASSOCIATED WITH HYDROGEN FLUORIDE ALKYLATION REACTOR/SETTLER

Equipment Item	Equipment Specification	Reference
VESSELS AND MACHINERY:		
Reactor/Settler	Gravity Flow Reactor/Settler System	38
Feed Dryers	Sieve Dryers or Equivalent on Reactor Feed Streams	38
PIPING AND VALVES:		
Relief Valve	2 in. x 3 in. Class 300 Inlet and Outlet Flange, Angle Body, Closed Bonnet With Screwed Cap, Carbon Steel Body, Monel® Trim	40
Rupture Disk	2 in. Monel® Disk and Carbon Steel Holder	41,46,47
INSTRUMENTATION:		
Temperature Sensor	Thermocouple and Associated Thermowell	37,40,43
Temperature Alarm	Indicating and Audible Alarm	40,45,50
Temperature Switch	Two-Stage Switch with Independently Set Actuation	37,43
Remote Temp. Indicator	Transmitter and Associated Electronics Indicator	37,43
Remote Press. Indicator	Transducer, Transmitter and Electronic Indicator	37,43
Flow Control Loop	2 in. Globe Control Valve, Monel® Trim, Flowmeter and PTD Controller	37,43
Flow Interlock System	Solenoid Valve, Switch, and Relay System	37,40,43, 45
Agitation Detection System and Alarm	Temperature Sensor Indicator and Alarm System for Phillips Reactor/Settler Design, Mechanical Agitation Detector for Others	37,43
Mixing Interlock System	Solenoid Valve, Switch, and Relay System	37,40,43, 45
pH Monitoring System	Electrode, Electrode Chamber, Amplifier-Transducer and Indicator	37,49
Moisture Monitoring System	Capacitance or Infrared Absorption System	49

(Continued)

TABLE 4-19 (Continued)

Equipment Item	Equipment Specification	Reference
DIKING:	Level #1: 6 in. High Concrete Curbing Level #2: 3 ft High Concrete Retaining	45
SCRUBBER:	Level #1 Spray Tower, Monel® Construction, Water Sprays, 8 ft. x 24 ft. Level #2 Spray Tower, Monel® Construction, Alkaline Sprays	51

TABLE 4-20. DETAILS OF MATERIAL AND LABOR COSTS ASSOCIATED WITH BASELINE HYDROGEN FLUORIDE ALKYLATION REACTOR/SETTLER SYSTEM

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
EQUIPMENT:					
Vessels and Machinery:					
Reactor/Settler					
Feed Dryers (2)					
Centrifugal Pumps (3)					
Total Vessels and Machinery[a]	700,000	315,000	1,015,000	254,000	1,459,000
Piping and Valves:[a]	252,000	210,000	462,000	115,000	664,000
INSTRUMENTATION:[a]	158,000	52,000	210,000	52,000	302,000
TOTAL COSTS	1,110,000	577,000	1,687,000	421,000	2,425,000

[a] Costs are based on using cost factors from Peters and Timmerhaus (37) and a total fixed capital cost of $10.06 million (1986 basis) (38) for a 147,000 gal/day alkylate capacity plant.

TABLE 4-21. DETAILS OF MATERIAL AND LABOR COSTS ASSOCIATED WITH LEVEL 1 HYDROGEN FLUORIDE ALKYLATION REACTOR/SETTLER SYSTEM

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
EQUIPMENT:					
Vessels and Machinery:					
Reactor/Settler					
Feed Dryers (2)					
Centrifugal Pumps (3)					
Total Vessels and Machinery[a]	1,270,000	571,000	1,841,000	460,000	2,646,000
Piping and Valves:[a]	492,000	164,000	656,000	164,000	943,000
Relief Valve	1,300	50	1,350	340	2,000
INSTRUMENTATION:[a]	158,000	52,000	210,000	52,000	302,000
Temperature Sensor	200	50	250	60	360
Temperature Alarm	200	50	250	60	360
Remote Temperature Indicator	1,000	250	1,250	310	1,800
Remote Pressure Indicator	1,000	250	1,250	310	1,800
Flow Control Loops (2)	6,000	1,500	7,500	1,900	11,000
Agitation Detection System and Alarm	1,000	250	1,250	310	1,800
DIKING:					
Curbing Around Reactor	500	350	850	210	1,200
SCRUBBER:					
Water Scrubber	125,000	56,000	181,000	45,000	260,000
TOTAL COSTS	2,056,000	846,000	2,902,000	725,000	4,172,000

[a] Costs are based on using cost factors from Peters and Timmerhaus (37) and a total fixed capital cost of $10.06 million (1986 basis) (38) for a 147,000 gal/day alkylate capacity plant.

TABLE 4-22. DETAILS OF MATERIAL AND LABOR COSTS ASSOCIATED WITH LEVEL 2 HYDROGEN FLUORIDE ALKYLATION REACTOR/SETTLER SYSTEM

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
EQUIPMENT:					
Vessels and Machinery:					
Reactor/Settler					
Feed Dryers (2)					
Centrifugal Pumps (3)					
Total Vessels and Machinery[a]	1,270,000	571,000	1,841,000	460,000	2,646,000
Piping and Valves:[a]	492,000	164,000	656,000	164,000	943,000
Relief Valves (2)	2,600	100	2,700	680	4,000
Rupture Disk	1,500	100	1,600	400	2,300
INSTRUMENTATION:[a]	158,000	52,000	210,000	52,000	302,000
Temperature Sensor	200	50	250	60	360
Temperature Alarm	200	50	250	60	360
Temperature Switch	300	75	375	95	540
Remote Temperature Indicator	1,000	250	1,250	310	1,800
Remote Pressure Indicator	1,000	250	1,250	310	1,800
Flow Control Loops (2)	6,000	1,500	7,500	1,900	11,000
Flow Interlock System	1,000	250	1,250	310	1,800
Agitation Detection System and Alarm	1,000	250	1,250	310	1,800
Mixing Interlock System	1,000	250	1,250	310	1,800
pH Monitoring System	5,000	1,300	6,300	1,600	9,000

(Continued)

TABLE 4-22 (Continued)

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
Moisture Monitoring System	5,000	1,300	6,300	1,600	9,000
All Loops on Computer Control[b]	105,000	35,000	140,000	35,000	201,000
DIKING:					
Retaining Wall	900	1,200	2,100	530	3,000
SCRUBBER:					
Alkaline Scrubber	150,000	67,000	217,000	54,000	312,000
TOTAL COSTS	2,202,000	896,000	3,098,000	775,000	4,453,000

[a] Costs are based on using cost factors from Peters and Timmerhaus (37) and a total fixed capital cost of $10.06 million (1986 basis) (38) for a 147,000 gal/day alkylate capacity plant.

[b] Computer Control costs are determined using cost estimating factors from Valle-Riestra (39).

TABLE 4-23. FORMAT FOR TOTAL FIXED CAPITAL COST

Item No.	Item	Cost
1	Total Material Cost	-
2	Total Labor Cost	-
3	Total Direct Cost	Items 1 + 2
4	Indirect Cost Items (Engineering & Construction Expenses)	0.35 x Item 3[a]
5	Total Bare Module Cost	Items (3 + 4)
6	Contingency	(0.05 x Item 5)[b]
7	Contractor's Fee	0.05 x Item 5
8	Total Fixed Capital Cost	Items (5 + 6 + 7)

[a] For storage facilities, the indirect cost factor is 0.35. For process facilities, the indirect cost factor is 0.25.

[b] For storage facilities, the contingency cost factor is 0.05. For process facilities, the contingency cost factor is 0.10.

fixed capital cost, other costs obtained by using factors are added to the total direct costs.

The first group of other cost elements is indirect costs. These include engineering and supervision, construction expenses, and various other expenses such as administration expenses. These costs are computed by multiplying total direct costs by a factor shown in Table 4-23. The factor is approximate, is obtained from the cost literature, and is based on previous experience with capital projects of a similar nature. Factors can have a range of values and vary according to technology area and for individual technologies within an area. Appropriate factors based on judgement and experience were selected for this report.

When the indirect costs are added to the total direct costs, total bare module cost is obtained. Some additional cost elements such as contractor's fee and contingency, are calculated by applying and adding appropriate factors to the total bare module cost, as shown in Table 4-23, to obtain the total fixed capital cost.

Annual Cost--Annual costs are obtained for each equipment item by applying a factor for both capital recovery and for maintenance expenses to the direct cost of each equipment item. Table 4-24 defines the cost elements and the appropriate factors comprising these costs. Additional annual costs are incurred for procedural items such as valve and vessel inspections, for example. The sum of these individual costs equals the total annual cost.

Sources of Information--

Costs presented in this report are derived from cost information in existing published sources and also from recent vendor information. The objective of this effort was to present cost levels for hydrogen fluoride process and storage facilities using the best costs for available sources. The primary sources of cost information are Peters and Timmerhaus (37), Chemical Engineering (52), and Valle-Riestra (38) supplemented by other sources and

TABLE 4-24. FORMAT FOR TOTAL ANNUAL COST

Item No.	Item	Cost
1	Total Direct Cost	-
2	Capital Recovery on Equipment Items	0.163 x Item 1
3	Maintenance Expense on Equipment Items	0.01 x Item 1
4	Total Procedural Items	-
5	Total Annual Cost	Items (2 + 3 + 4)

references where necessary. Adjustments were made to update all costs to a June 1986 dollar basis. For some equipment items, well-documented costs were not available and they had to be developed from component costs.

Costs in this document reflect the "typical" or "average" representation for specific equipment items. This restricts the use of data in this report to:

- Preliminary estimates used for policy planning;
- Comparison of relative costs of different levels or systems; and
- Approximations of costs that might be incurred for a specific application.

The costs in this report are considered to be "order of magnitude" with a ±50 percent margin. This is because costs are based on preliminary estimates and many are updated from literature sources. Large departures from the design basis of a particular system presented in this manual or the advent of a different technology might cause the system cost to vary more than this. If used as intended, however, this document will provide a reasonable source of preliminary cost information for the facilities covered.

When comparing costs in this manual to those from other references, the user should be sure the design bases are comparable and that the capital and annual costs as defined here are the same.

Cost Updating--

All costs in this report are expressed in June 1986 dollars. Costs reported in the literature were updated using cost indices for materials and labor.

Costs expressed in base-year dollars may be adjusted to dollars for another year by applying cost indices as shown in the following equation:

$$\text{new base-year cost} = \text{old base-year cost} \times \frac{\text{new base year index}}{\text{old base year index}}$$

The Chemical Engineering (CE) Plant Cost Index was used in updating costs for this report. For June 1986, the index is 316.3.

Equipment Costs--

Most of the equipment costs presented in this manual were obtained directly from literature sources of vendor information and correspond to a specific design standard. Special cost estimating techniques, however, were used in determining the costs associated with vessels, piping systems, scrubbers, diking, and enclosures. The techniques used are presented in the following subsections of this manual.

Vessels--The total purchased cost for a vessel, as dollars per pound of weight of fabricated unit free on board (f.o.b.), with carbon steel as the basis (January 1979 dollars) were determined using the following equation from Peters and Timmerhaus (26):

$$\text{Cost} = [50(\text{Weight of Vessel in Pounds})^{-0.34}][\text{Weight of Vessel in Pounds}]$$

The vessel weight is determined using appropriate design equations as given by Peters and Timmerhaus (37), that allow for wall thickness adjustments for corrosion allowances, for example. The vessel weight is increased by a factor of 0.15 for horizontal vessels and 0.20 for vertical vessels to account for the added weight of nozzles, manholes, and skirts or saddles. Appropriate factors are applied for different materials of construction as given in Peters and Timmerhaus (37). Vessel costs are updated using cost factors. Finally a shipping cost amounting to 10 percent of the purchased cost is added to obtain the delivered equipment cost.

Piping--Piping costs were obtained using cost information and data presented by Yamartino (53). A simplified approach is used in which it is assumed that a certain length of piping containing a given number of valves, flanges, and fittings is contained in the storage or process facility. The data presented by Yamartino (53) permit cost determinations for various lengths, sizes, and types of piping systems. Using these factors, a representative estimate can be obtained for each of the storage and process facilities.

Diking--Diking costs were estimated using Mean's Manual (45) for reinforced concrete walls. The following assumptions were made to determine the costs. The dike contains the entire contents of a tank in the event of a leak or release. Two dike sizes are possible: a three-foot high dike, six-inches thick and a top-of-tank height dike ten inches thick. The tanks are raised off the ground and are not volumetrically included in the volume enclosed by the diking. These assumptions facilitate cost determination for any size diking system.

Enclosures--Enclosure costs were estimated using Mean's Manual (45) for both reinforced concrete and steel-walled buildings. The buildings are assumed to enclose the same area and volume as the top-of-tank height dikes. The concrete building is ten-inches thick with a 26-gauge steel roof and a metal door. The steel building has 26 gauge roofing and siding and metal door. The cost of a ventilation system was determined using a typical 1,000 scfm unit and doubling the cost to account for duct work and requirements for the safe enclosure of hazardous chemicals.

Scrubbers--Scrubber costs were estimated using the following equation from the Gard (51) manual for spray towers based on the actual cubic feet per minute of flow at a chamber velocity of 600 feet/minute.

$$\text{Costs} = 0.235 \times (\text{ACFM} + 43{,}000)$$

A release rate of 10,000 ft^3/minute was assumed for the storage vessel systems and an appropriate rate was determined for process system based on the quantity of hazardous chemicals present in the system at any one time. For the hydrogen fluoride alkylation system, a release rate of 36,000 ft^3/minute was assumed. In addition to the spray tower, the costs also include pumps and a storage tank for the scrubbing medium. The costs presented are updated to June 1986 dollars.

Installation Factors--

Installation costs were developed for all equipment items included in both the process and storage systems. The costs include both the material and labor costs for installation of a particular piece of equipment. The costs were obtained directly from literature sources and vendor information or indirectly by assuming a certain percentage of the purchased equipment cost through the use of estimating factors obtained from Peters and Timmerhaus (37) and Valle-Riestra (39). Table 4-25 lists the cost factors used or the reference from which the cost was obtained directly. Many of the costs obtained from the literature were updated to June 1986 dollars using a 10 percent per year rate of increase for labor and cost indices for materials associated with installation.

TABLE 4-25. FORMAT FOR INSTALLATION COSTS

Equipment Item	Factor or Reference
Vessels:	
Storage Tank	0.45
Expansion Tank	0.25
Piping and Valves:	
Pipework	Ref. 59
Expansion Loop	Ref. 40
Reduced Pressure Device	Ref. 40
Check Valves	Ref. 40
Gate Valves	Ref. 40
Ball Valves	Ref. 40
Excess Flow Valves	Ref. 40
Angle Valves	Ref. 45
Relief Valves	Ref. 40
Rupture Disks	Ref. 40
Process Machinery:	
Centrifugal Pump	0.43
Gear Pump	0.43
Instrumentation:	
All Instrumentation Items	0.25
Enclosures:	Ref. 45
Diking:	Ref. 45
Scrubbers:	0.45

SECTION 5

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APPENDIX A

ELECTROMOTIVE SERIES OF METALS

TABLE A-1. ELECTROMOTIVE SERIES OF METALS

Least noble (most easily corroded)
Lithium
Potassium
Rubidium
Calcium
Sodium
Magnesium
Plutonium
Beryllium
Uranium
Aluminum
Titanium
Zirconium
Manganese
Tantalum
Zinc
Chromium
Iron
Cadmium
Nickel
Molybdenum
Tin
Lead
Tungsten
HYDROGEN
Copper
Mercury
Silver
Gold
Platinum
Palladium
Most noble (least easily corroded)

Source: Reference 54

APPENDIX B
GLOSSARY

This glossary defines selected terms used in the text of this manual which might be unfamiliar to some users or which might be used differently by different authors.

Accidental release: The unintentional spilling, leaking, pumping, purging, emitting, emptying, discharging, escaping, dumping, or disposing of a toxic material into the environment in a manner that is not in compliance with a plant's federal, state, or local environmental permits and/or results in toxic concentrations in the air that are a potential health threat to the surrounding community.

Cavitation: The formation and collapse of vapor bubbles in a flowing liquid. Specifically, the formation and collapse of vapor cavities in a pump when there is sufficient resistance to flow at the inlet side.

Chlorofluorocarbons: Organic compounds containing chlorine and/or fluorine atoms within the molecule.

Creep failure: Failure of a piece of metal as a result of creep. Creep is time dependent deformation as a result of stress. Metals will deform when exposed to stress. High levels of stress can result in rapid deformation and rapid failure. Lower levels of stress can result in slow deformation and protracted failure.

Deadheading: Closing or nearly closing or blocking the discharge outlet or piping of an operating pump or compressor.

Electromotive Series of Metals: A list of metals and alloys arranged according to their standard electrode potential which also reflects their relative corrosion potential.

Facility: A location at which a process or set of processes are used to produce, refine or repackage chemicals, or a location where a large enough inventory of chemicals are stored so that a significant accidental release of a toxic chemical is possible.

Hazard: A source of danger. The potential for death, injury or other forms of damage to life and property.

Hygroscopic: Readily absorbing and retaining moisture, usually in reference to readily absorbing moisture from the air.

Killed steel: Steel that is deoxidized with a strong deoxidizing agent such a silicon or aluminum in order to reduce the oxygen content to such a level that no reaction occurs between carbon and oxygen during solidification. Such a steel will have a smaller grain size than a steel that is not killed. The grain size affects the physical and chemical properties of the steel. Fully-killed steel is fully deoxidized and has a smaller grain size than semi-killed steel which is partially deoxidized and has a smaller grain size than steel that is not killed.

Mild steel: Carbon steel containing a maximum of about 0.25% carbon. Mild steel is satisfactory for use where severe corrodants are not encountered or where protective coatings can be used to prevent or reduce corrosion rates to acceptable levels.

Mitigation: Any measure taken to reduce the severity of the adverse effects associated with the accidental release of a hazardous chemical.

Olefinic hydrocarbons: A specific subgroup of aliphatic hydrocarbons sharing the common characteristic of at least one unsaturated carbon-to-carbon atomic bond in the hydrocarbon molecule. Aliphatic hydrocarbons are hydrocarbons with a basic straight or branched chain structure in contrast with ring structured compounds.

Passivation film: A layer of oxide or other chemical compound of a metal on its surface that acts as a protective barrier against corrosion or further chemical reaction.

Plant: A location at which a process or set of processes are used to produce, refine or repackage chemicals.

Prevention: Design and operating measures applied to a process to ensure that primary containment of toxic chemicals is maintained. Primary containment means confinement of toxic chemicals within the equipment intended for normal operating conditions.

Process: The sequence of physical and chemical states and operations for the production, refining, or repackaging of chemicals.

Process machinery: Process equipment such as pumps, compressors, or agitators that would not be categorized as piping or vessels.

Protection: Measures taken to capture or destroy a toxic chemical that has breached primary containment, but before an uncontrolled release to the environment has occurred.

Toxicity: A measure of the adverse health effects of exposure to a chemical.

APPENDIX C
METRIC (SI) CONVERSION FACTORS

TABLE C-1. METRIC (SI) CONVERSION FACTORS

Quantity	To Convert From	To	Multiply By
Length:	in	cm	2.54
	ft	m	0.3048
Area:	in^2	cm^2	6.4516
	ft^2	m^2	0.0929
Volume	in^3	cm^3	16.39
	ft^3	m^3	0.0283
	gal	m^3	0.0038
Mass (weight):	lb	kg	0.4536
	short ton (ton)	Mg	0.9072
	short ton (ton)	metric ton (t)	0.9072
Pressure:	atm	kPa	101.3
	mm Hg	kPa	0.133
	psia	kPa	6.895
	psig	kPa*	(P(psig)+14.696) X(6.895)
Temperature:	°F	°C*	(5/9)X(°F-32)
	°C	K*	°C+273.15
Caloric Value:	Btu/lb	kJ/kg	2.326
Enthalpy:	Btu/lbmol	kJ/kgmol	2.326
	kcal/gmol	kJ/kgmol	4.184
Specific-Heat Capacity:	Btu/lb-°F	kJ/kg-°C	4.1868
Density:	lb/ft^3	kg/m^3	16.02
	lb/gal	kg/m^3	119.8
Concentration:	oz/gal	kg/m^3	
	quarts/gal	cm^3/m^3	25,000
Flowrate:	gal/min	m^3/min	0.0038
	gal/day	m^3/day	0.0038
	ft^3/min	m^3/min	0.0283
Velocity:	ft/min	m/min	0.3048
	ft/sec	m/sec	0.3048
Viscosity:	centipoise (CP)	kg/m-s	0.001

*Calculate as indicated.